Library

STRUCTURAL GEOLOGY OF BLACK GAP AREA,

BREWSTER COUNTY, TEXAS

APPROVED:

[W. Muehlberger]
(Signature of supervising professor)

[R. DeFord]

[P. Flawn]

[C.I. Smith]

STRUCTURAL GEOLOGY OF BLACK GAP AREA,

BREWSTER COUNTY, TEXAS

A

DISSERTATION

Presented to the Faculty of the Graduate School of
The University of Texas in Partial Fulfillment
of the Requirements
For the Degree of
DOCTOR OF PHILOSOPHY

By

Billy Eugene St. John, B.S., M.A.

Austin, Texas

August 1965

## PREFACE

How much of this dissertation is my work? The months in the field, the hours and days spent on the microscope, drawing maps, writing and re-writing are mine, but what of the ideas? I doubt if any written work of this sort reflects the thinking of only the writer. My ideas and interpretations have followed a path much like that a ping-pong ball would follow if dropped into a funnel. Ideas bounce around, seemingly at random but at all times channeled toward a focal point by the boundaries of experience of supervisors, faculty members, and fellow students. To these people I owe an unpayable debt and hope they realize the magnitude of my gratitude.

First and foremost is my supervisor, Professor W. R. Muehlberger. Not only an expert in his field but a close and lasting friend. Professor R. K. DeFord and Dr. P. T. Flawn, committee members, gave unstintingly of their time, enthusiasm, and constructive criticism. C. I. Smith, stratigrapher with the Shell Development Company and member of the dissertation committee, gave direction in the field and was invaluable during preparation of the section concerning stratigraphy. Dr. Muehlberger and W. T. Haenggi of The University of Texas spent four days in the field with me as did Dr. Frank Lozo

and C. I. Smith of Shell Development Company.

Other faculty members of the Department of Geology, The University of Texas, who gave generously of their time and talents include Drs. D. S. Barker, R. L. Folk and J. H. Mackin. Dr. K. P. Young identified the fossils.

Dr. R. A. Maxwell, Texas Bureau of Economic Geology, has spent much of his life studying the geology in and around the Big Bend National Park. I am indebted to him for his help and information.

The Texas Bureau of Economic Geology furnished field expenses, field vehicle, aerial photographs, and thin-sections for this study. J. W. Macon, cartographer for the Bureau, supervised preparation of the final map. Photogrammetry, compilation, and scribing of the map was by Dan F. Scranton.

Fellow students with whom I advantageously discussed ideas included Walter T. Haenggi, A. Burke Spencer, E. Les Trice, and Ed J. Dickerson.

Mr. E. Walker, of the Texas Parks and Wildlife Commission office in Austin, gave permission to work the Black Gap Wildlife Management Area. The Brewster County representatives, Fred Guliher, George Litton, Tom Halley, Sam Brownlee, and Durwood Avery, were more than courteous.

Land owners and managers gave permission to work

their property and extended many courtesies as only those from ranching country seem to do. Among these are Frank Lasater, Pache and David Adams, Guy Stillwell, Delmer Collins, Steve Stumburgh, and Bud Roark. M. C. and P. R. Overton, and Sam Caveness, owners and foreman of the Dove Mountain Ranch, allowed me to stay at their ranch headquarters. Of these, several became close friends.

The project was originally proposed in 1960 by Professor W. R. Muehlberger and at that time included the Maravillas Canyon, Dove Mountain, Bullis Gap, and Reagan Canyon quadrangles. The project was postponed during three years of overseas employment and resumed upon my return to graduate school in 1963. In the meantime, Dr. Maxwell's map of the Big Bend National Park had been completed and is now in press. Altering the map area to its present shape in order to conform with Dr. Maxwell's eastern boundary resulted in a more logical geologic problem than the original project.

The dissertation was submitted to the editorial committee in May 1965.

Billy Eugene St. John
August 1965

STRUCTURAL GEOLOGY OF BLACK GAP AREA,
BREWSTER COUNTY, TEXAS

by

Billy Eugene St. John

## A B S T R A C T

The outcropping strata of the Black Gap area are principally Cretaceous, but include Tertiary volcanic rock and Quaternary alluvium. No rocks older than the Cretaceous Glen Rose Limestone crop out within the map area, although Paleozoic strata of the Ouachita System are exposed near the northwest corner.

The area is on the plunging northwest end of the Serrania del Burro and astride the frontal and interior zones of the Ouachita System. To the north, northwest-trending monoclines and an east-trending igneous belt border the Marathon Basin; to the south lies the block-faulted and reverse-faulted eastern margin of the Big Bend structural belt.

The mosaic of structural features is the result of several events. Uplift of the Sierra del Carmen followed by décollement to the northeast across the Black Gap area formed the asymmetric Stillwell anticline and other folds. Rejuvenation of northeast-trending Paleozoic faults is probably the cause of the northeast-striking Dove Mountain Ranch

anticline and associated faults. The re-occurrence of northwestward thrusting of the underlying Paleozoic strata, possibly resulting from sub-crustal activity, compressed the strata, forming conjugate shear sets striking approximately N. 20° W. and N. 75° W. in the massive Cretaceous limestones. Release of compression resulted in block faulting along the zones of weakness set up by the compression. A left-lateral rift movement accompanied the normal faulting.

C O N T E N T S

TEXT

Page

## ILLUSTRATIONS

Figure | Page



Plate

| Plate | | Page |
|---|---|---|

# INTRODUCTION

The outcropping rocks of the Black Gap area are principally Cretaceous. Paleozoic strata crop out north of the area in the northwest quarter of the Dove Mountain quadrangle and in a small exposure near Persimmon Gap in the northwest corner of the map area. Tertiary volcanic rocks and Quaternary alluvium compose the remaining strata.

The area is on the north end of the Coahuila Platform and astride the boundary between the frontal and interior zones of the Ouachita System (fig. 19). Structurally, it is a transition zone between northwest-trending monoclines and an east-trending igneous belt to the north, and northwest-trending down-to-the-northeast fault blocks to the south.

Basically, the area is a large northwest-trending graben flanked by a stable block to the northeast and a series of tilted fault blocks to the southwest. The stable block and graben are terminated to the north by a large northeast-trending faulted anticline. Outcrops within the graben expose the youngest Cretaceous rocks and are capped by a mass of Tertiary extrusive basalt.

# LOCATION

The wedge-shaped Black Gap area in southern Brewster County, Texas, occupies approximately 450 square miles east of the Big Bend National Park. The southwestern boundary of the map area is the eastern boundary of the park; the southeastern boundary is the Rio Grande; the north boundary is drawn at lat 29°45' N. The area lies in the Trans-Pecos province and the climate, as well as the flora and fauna, are similar throughout this arid to semiarid region (McDougall and Sperry, 1951).

The map area includes all the Maravillas Canyon quadrangle and parts of Reagan Canyon, Bone Spring, and Chisos Mountains quadrangles.

The area derives its name from a water gap cut through folded Tertiary extrusive basalt which faces the Black Gap Wildlife Management Area headquarters (fig. 1). The wildlife area covers 100,000 acres and is included in the central part of the map area.

Figure 1. View to northeast through Black Gap from a point near Black Gap Wildlife Management Area headquarters.

State Highway 385 extends from Marathon to the Big Bend National Park. Access to the area is via a county-maintained graded road that passes from the highway south through the area to La Linda Crossing at the mouth of Heath Canyon. Hunting- and fishing-camp roads in the wildlife area and work roads on the ranches cover the region so that one can drive within a half-day walk of any part of the map area. A county graded road parallel with and immediately north of the northern boundary gives access to the northern part of the area.

## PREVIOUS AND CURRENT WORK

R. T. Hill (1900) discussed general physiographic features of this area in his study of the physical geography of Texas. He was, however, studying the state as a whole and did not go into detail. An earlier worker in the Trans-Pecos region was von Steeruwitz (1891), but he did not work as far south as the Black Gap area.

Udden (1907) made the first stratigraphic studies, and it is upon his work that current nomenclature and understanding of gross features are based. Baker and Bowman (1917) entered this region during their study of the southeastern Front Range, but their contribution to the area of this report was not as significant as Udden's.

King (1937) accomplished the next major work in this area with his study of the Marathon Basin. His area includes the Monument Springs and Marathon quadrangles plus parts of surrounding quadrangles. King was interested in the Paleozoic strata and structure of the Marathon Basin. His treatment of the Cretaceous rocks around the rim of the basin is not as detailed as his study of the Paleozoic strata.

Eifler (1943) and Graves (1954) mapped 15-minute quadrangles to the north and northwest of the Black Gap area. Their work is referred to in many places in this report.

Several other 15-minute quadrangle maps have been published; for these and work in progress, see figure 2.

Numerous unpublished masters theses for areas of varying shapes and sizes within Brewster County are in the libraries of The University of Texas, Texas Agricultural and Mechanical University, and elsewhere (Brown, 1963). Of these, Wilson and Shambaugh's (1951) study of a part of the Black Gap area must be mentioned. Their map served as a starting point.

International Boundary and Water Commission geologists have mapped a strip along the Rio Grande extending about three miles from either side of the river (fig. 2). The interpretation presented herein differs from their map only in minor respects.

The West Texas Geological Society has published several guidebooks dealing with Trans-Pecos Texas (1941, 1949, and 1955), and the one for the Big Bend National Park is of special interest (Lonsdale and others, 1955). A comprehensive report on the geology of the Big Bend National Park by Maxwell and others is in preparation by the Bureau of Economic Geology. This work redefines numerous stratigraphic units and proposes the nomenclatural scheme used in this report.

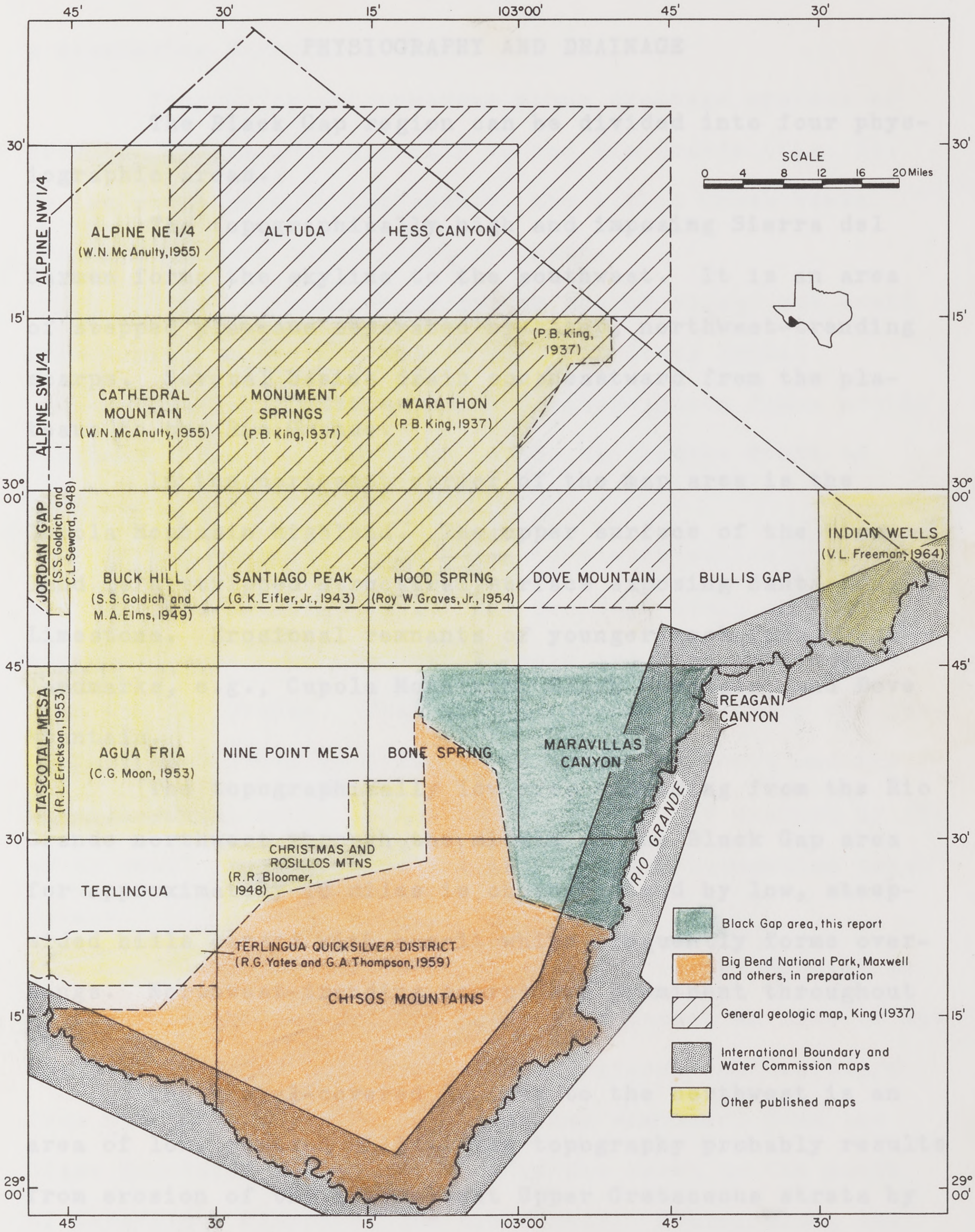



Figure 2. Geologic maps in Brewster County, Texas, published or in preparation.

## PHYSIOGRAPHY AND DRAINAGE

The Black Gap region can be divided into four physiographic areas.

The topographically high and imposing Sierra del Carmen forms the skyline to the southwest. It is an area of stepped plateaus separated by steep, northwest-trending scarps. Several basins drain southeastward from the plateaus to the Rio Grande.

In the northeast corner of the map area is the Cupola Mountain highland. The upper surface of the highland is a stripped structural surface exposing Santa Elena Limestone. Erosional remnants of younger rock form local landmarks, e.g., Cupola Mountain, Black Mountain, and Dove Mountain.

The topographically low area extending from the Rio Grande northwest through the middle of the Black Gap area for approximately 18 miles is characterized by low, steep-sided hills capped with basalt which frequently forms overhangs. Northwest-trending scarps are prominent throughout this area.

The gravel-covered lowland to the northwest is an area of low, rounded hills. The topography probably results from erosion of the incompetent Upper Cretaceous strata by a meandering Maravillas Creek.

Four major and numerous minor drainage systems of Brewster County lead directly to the Rio Grande (fig. 3). In the north part of the county, the Alpine Creek basin drains northward toward Fort Stockton.

The Terlingua Creek system drains almost due south from Alpine to the Rio Grande south of Study Butte.

The San Francisco Creek drainage basin flows south-southeast from near Marathon to the Rio Grande south of Sanderson.

The Tornillo Creek basin is almost entirely within the Big Bend National Park. The drainage basin extends north and east from the Chisos Basin and drains southward into the Rio Grande. That part of the park between the Terlingua Creek drainage basin to the west and north and the Tornillo Creek basin to the north and east is drained by 20 or so small creeks. None are large enough to mention separately.

Of major interest to this report is the Maravillas Creek drainage basin. This basin encompasses an area of approximately 2,100 square miles that extends southeastward from near Alpine in the northwest and southward from the Glass Mountains beyond Marathon in the north to the mouth of Maravillas Canyon at the Rio Grande. Gravel along the

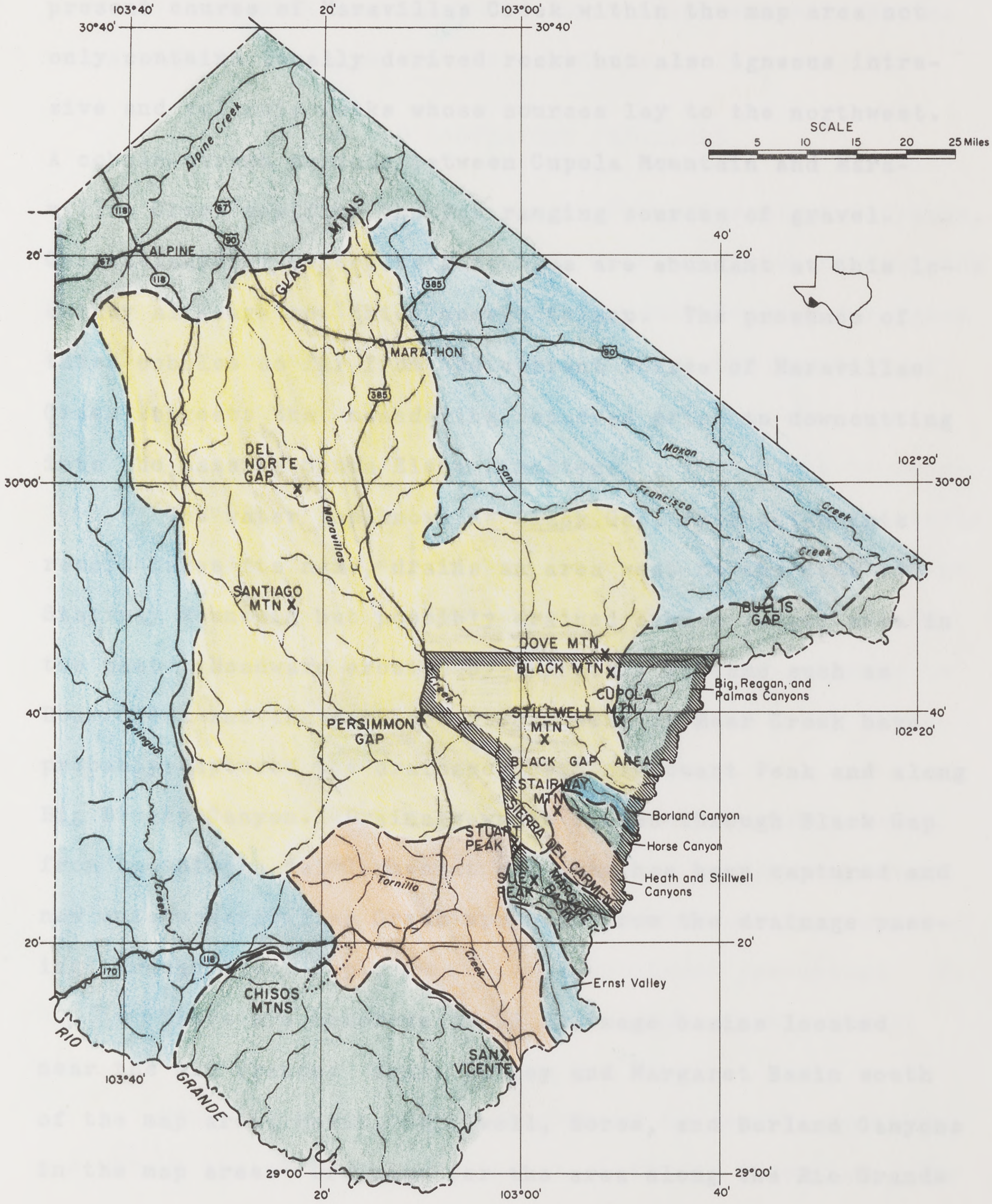



Figure 3. Drainage basins of Brewster County, Texas.

present course of Maravillas Creek within the map area not only contains locally derived rocks but also igneous intrusive and volcanic rocks whose sources lay to the northwest. A cobble-strewn surface between Cupola Mountain and Maravillas Creek verifies the far ranging sources of gravel. Quartz-sanidine welded-tuff cobbles are abundant at this locality although not thick enough to map. The presence of these cobbles so far from the current course of Maravillas Creek suggests that meandering occurred prior to downcutting into the massive Santa Elena Limestone.

The water gap known as Black Gap, from which this report takes its name, drains an area west to the foot of Stairway Mountain but possibly drained a much larger area in the past. Headward erosion by tributary streams such as Bear Creek and the nameless stream west of Bear Creek have probably captured the drainage north of Stuart Peak and along Big Brushy Canyon. Drainage which flowed through Black Gap from the Sierra del Carmen at one time has been captured and now enters Maravillas Creek upstream from the drainage passing through Black Gap.

There are numerous small drainage basins located near the Rio Grande: Ernst Valley and Margaret Basin south of the map area; Heath, Stillwell, Horse, and Borland Canyons in the map area. Drainage for the area along the Rio Grande between the Maravillas Creek and San Francisco Creek systems is through Big, Reagan, and Palmas Canyons.

## FIELD AND LABORATORY PROCEDURE

Stereo-paired U. S. Army Air Force aerial photographs, scale 1:48,000, taken in 1949, were used as a base for mapping in the field. The Texas Bureau of Economic Geology furnished the photographs which were obtained through the courtesy of the Edgar Tobin Aerial Surveys.

I used a Brunton compass and five-foot stick to measure stratigraphic sections. I collected and described briefly samples of each lithology in the field. Binocular microscope examination in the laboratory supplements field descriptions for those given on the composite section (pl. 3). Carbonate classification follows Folk (1961, 1962). Rock color designations are after Goddard and others (1951).

There are 23 thin sections; 5 of sedimentary rocks, 10 of metamorphic rocks, and 8 of igneous intrusive and volcanic rocks. Initial mineral identification was supplemented by a 300-point count to determine constituent percentage. D. S. Barker made an X-ray analysis of a sample from a basalt plug.

Elevation points were determined by profile sections made every two miles in a northeast-southwest direction. The structure contour map (pl. 2) is based on data gained from these profiles. The fault pattern shown on the structure contour map is from the geologic map.

Fossils were collected throughout the sections measured. Elsewhere, single specimens were collected wherever found. K. P. Young identified the fossils.

# S T R A T I G R A P H Y

## PRE-CRETACEOUS ROCKS

### Precambrian Rocks

No Precambrian rock is exposed in the Black Gap area and little is known about the Precambrian rocks of the surrounding region.

Numerous writers (for reference, see Flawn and others, 1961, p. 53) have commented on the occurrence of granite and rhyolite boulders of probable Precambrian age in the Haymond boulder beds near Haymond Station, east of Marathon, 25 miles north of the map area. Muehlberger and others (in preparation) report two ages from a granite-gneiss boulder fron near Housetop Mountain. They assume that the total-rock Rb-Sr age of 570 million years (early Cambrian) is the age of the origin of the rock and believe that the biotite K-Ar age of 360 million years represents the age of the latest metamorphism of the rock.

### Paleozoic Rocks

Near Persimmon Gap in the northwest corner of the map area is an outcrop of limestone, shale, novaculite, and orthoquartzite. Udden (1907, p. 18) mentioned this outcrop but assigned no age other than including his discussion of it in a section on Paleozoic rocks. Baker and Bowman (1917, p. 103) assigned the outcrop to the Tesnus Formation of Pennsylvanian age. Lonsdale and others (1955, p. 56) who mapped the area, depicted it as an area of thrust faults involving Maravillas, Caballos, and Tesnus Formations ranging in age from Ordovician to Carboniferous.

C. L. Baker discovered outcrops of schist east of the village of Boquillas, Mexico (Böse, 1923, p. 113). Flawn and others (1961, p. 99) reported ages of 240 and 370 million years from the schist. These ages indicate that metamorphism of the rock occurred during the Paleozoic Era but give no information regarding the age of origin of the rock.

Paleozoic strata undoubtedly extend beneath the Black Gap area but insufficient outcrops and lack of subsurface data preclude detailed discussion.

King (1937) discussed the Paleozoic strata of the Marathon Basin in detail, both as to stratigraphy and structure. Flawn and others (1961) extended this study into the subsurface with available well data plus exposures in Mexico.

## Triassic and Jurassic Record

Post-Paleozoic erosion planed the deformed Paleozoic strata over an extensive area. Hill (1901, p. 363) named the erosional surface the Wichita paleoplain.

The only pre-Cretaceous Mesozoic rock reported in this region is the Bissett Conglomerate (King, 1927, p. 212) which crops out along the northwest flank of the Glass Mountains 45 miles north of the map area. Diastrophism and erosion initiated at the end of the Paleozoic Era possibly extended through the Triassic and Jurassic Periods.

## CRETACEOUS ROCKS

Unconformably overlying the deformed Paleozoic rocks are Comanchean strata. These marine deposits continue upward into the Gulf series whose uppermost section, missing in the Black Gap area, is typified by a continental clastic facies.

Stratigraphic nomenclature of the Cretaceous rocks is that set forth by Maxwell and others (in preparation) in their study of the geology of the adjoining Big Bend National Park. They also discuss facies changes and correlation of rocks west of the Big Bend National Park.

### Comanchean Series

Approximately 3,000 feet of Cretaceous rock is exposed in the Black Gap area. Most of the section is massive limestone of Comanchean age. A distinct lithologic change

THE UNIVERSITY OF TEXAS
BUREAU OF ECONOMIC GEOLOGY
PETER T. FLAWN, DIRECTOR

PLATE III

COMPOSITE MEASURED SECTION FROM BLACK GAP AREA

between the Buda Limestone and Boquillas Formation marks the contact between the Comanchean and Gulfian strata.

## Glen Rose Limestone

Maxwell and others (in preparation) use Glen Rose Limestone for the thin-bedded rocks beneath the massive Del Carmen Limestone in the Big Bend National Park.

Thickness, lithology, and fossils.--The Glen Rose Limestone is the lowest Cretaceous formation exposed in the map area. It rests with angular unconformity on underlying Paleozoic strata to the north in the Hood Spring quadrangle (Graves, 1954, p. 16). Exposures of Glen Rose are found where the Rio Grande has deeply incised the Cretaceous rocks northeast from the mouth of Maravillas Creek and in the Sierra del Carmen in the southern part of the map area.

MS-3 includes an incomplete thickness of 733 feet of Glen Rose; the base is not exposed. At this locality, the formation consists predominantly of biomicrite with interbedded biosparite and calcareous clay. A foot-thick bed of quartz siltstone 161 feet below the top is the only siliciclastic rock in MS-3. Near the mouth of Big Canyon in the northeast part of the map area, approximately 25 feet of silty, fine-grained, ripple-marked sandstone (fig. 4) occurs in the upper part of the Glen Rose. There is a 14-foot caprinid bioherm near the base of MS-3.

Figure 4. Thin-bedded, ripple-marked sandstone in the upper part of the Glen Rose Limestone, exposed in the west wall of the Rio Grande Canyon 1/2 mile south of the mouth of Big Canyon.

*Orbitolina* cfr. *texana* Roemer is abundant throughout the lower 566 feet of the Glen Rose at MS-3. The composite section (pl. 3) records other fossils from the Glen Rose.

King (1937, p. 112-113) reported different thicknesses: 312 feet at Housetop Mountain, 500 feet along the south edge of the Marathon Basin, and 559 feet on the west side of the Basin in the Del Norte Mountains. He mentioned the abundant occurrence of *O. texana* and *Exogyra quitmanensis*.

King also remarked that Glen Rose beds terminate against the flanks of the Glass Mountains and that the Maxon Sandstone overlaps them.

In the Cochran Mountains, Eifler (1943, p. 1620) reported a thickness of 458 feet with a marly zone in the upper 150 feet, the whole section characterized by O. texana and E. quitmanensis.

Graves (1954, p. 16) measured a complete section 475 feet thick in the Hood Spring quadrangle. His section includes a basal conglomerate. Graves pointed out the abundance of O. texana and Porocystis globularis in the upper marly part of the section and rudistids in the lower, thick-bedded limestone section.

Freeman (1964) mapped Glen Rose Limestone to the northeast in the Indian Wells quadrangle but gave neither thickness nor fossil content. He termed it "gray limestone that crops out in bottom of Rio Grande Canyon."

Santiago Charleston[1] reported an incomplete Glen Rose thickness of 485 feet at Cerro el Barco, Mexico, across the Rio Grande slightly downstream from the mouth of Maravillas Creek, lat 29°36'43" N., long 102°43'25" W. (letter from C. I. Smith, 16 February 1965).

[1]Geologist, Petroleos Mexicanos, Monterrey, Mexico.

The Glen Rose probably thins northward through the Black Gap area toward the Glass Mountains. King (1937, p. 110) stated that the Glass Mountains stood as an asymmetric ridge during the advance of the Cretaceous sea. An increase of silt and sand to the north in the upper Glen Rose supports King's idea.

Origin.--General lithology, ripple marks, and plant fragments in the Glen Rose Limestone indicate a shallow water environment. The lower, rudistid-bearing limestone is a neritic facies, and the clayey, sandy upper section represents littoral, nearshore deposition.

## Absence of Maxon Formation

Baker and Bowman (1917, p. 113-114) discussed basal clastic Comanche beds in the Marathon region, describing a 40-foot sandstone around the east margin of the basin and a cross-bedded sandstone beneath the "Edwards" in the southeast corner of the basin. They did not name this unit, but King (1930, p. 92) named it Maxon Sandstone for exposures near Maxon Station, Brewster County, Texas.

I did not recognize a Maxon unit in the Black Gap area nor did Maxwell (oral communication, 1965) in the Big Bend National Park. At King's type locality 23 miles north of the map area the sandstone overlies and overlaps the Glen

Rose Limestone and underlies the "Edwards." King described the sandstone as medium- to coarse-grained, cross-bedded, and broken by joints. He found no fossils at the type locality.

Eifler (1943, p. 1622) described a 73-foot section in the north part of the Santiago Peak quadrangle (fig. 2) and 114 feet in the southeast corner. He mentioned prominent cross-bedding and large, weathered, joint blocks. Eifler correlated the Maxon with the Fredericksburg Group of central Texas on the basis of _Corbis_ and _Volvulina dolium_.

Graves (1954, p. 19) measured sections of Maxon Sandstone 115 and 157 feet thick 10 miles northwest of the map area. He described it as a gray to brown, fine- to medium-grained, friable to dense, cross-bedded sandstone with fossiliferous limestone lenses. Because of the gradational contact with the underlying Glen Rose Limestone and lack of definitive fossils, Graves correlated the Maxon Sandstone with the Trinity Group of central Texas.

Geologists of the International Boundary and Water Commission extended the Maxon Formation through the Black Gap area south into the Big Bend National Park. They described it as a gray, thin-bedded marl and limestone with thin, cross-bedded sandstone members. Freeman (1964) utilized their mapping in his compilation of the Indian Wells quadrangle but termed the unit "Maxon Limestone." Freeman described it as limestone and clayey limestone with subordinate sandstone and siltstone comprising about 10 percent of the unit. He gave an estimated thickness of 250 feet.

I do not believe that the Maxon Formation is present in the Black Gap area. The sandstone beneath the Telephone Canyon Formation in the northeast part of the map area consists of lenses or tongues within the upper Glen Rose Limestone. Possibly these are tongues that thicken and occur at progressively higher levels to the north. If so the relation must be similar to that shown in figure 5.

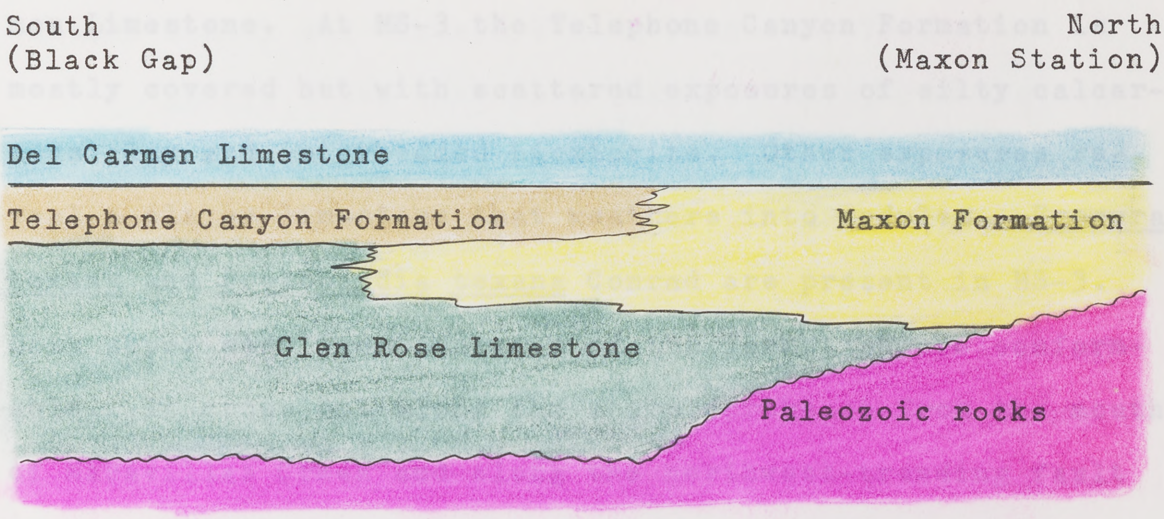



Figure 5. Possible facies relationship of Maxon Formation.

## Telephone Canyon Formation

The Telephone Canyon Formation derives its name from the exposure in Telephone Canyon where Heath Creek crosses the Sierra del Carmen near the southern boundary of the map area. Maxwell and others (in preparation) define this unit on the basis of stratigraphic relations in the Big Bend region and use a local name; other authors have used the term "Walnut-Comanche Peak" for the same rocks, thus implying a correlation with central Texas rocks which cannot be demonstrated.

Thickness, lithology, and fossils.--The Telephone Canyon is poorly exposed in the Black Gap area because of talus cover; MS-3, however, has an interval of 86 feet between the top of the Glen Rose and the base of the Del Carmen Limestone. At MS-3 the Telephone Canyon Formation is mostly covered but with scattered exposures of silty calcareous clay and interbedded biomicrite. Other exposures reveal a clayey limestone that weathers into nodules. *Exogyra texana* and *Protocardia texana* Conrad are present in MS-3. Both upper and lower contacts of the formation are conformable. It crops out along the scarp northeast from the mouth of Maravillas Creek and along the northwest-trending fault scarps of the Sierra del Carmen to the south. Typical of the latter exposure are the outcrops on the west side of Margaret Basin and along Heath Creek.

Graves (1954, p. 22) reported 57.5 feet of section but with neither the top nor bottom exposed. Freeman (1964) estimated a thickness of 60 feet for exposures in the Indian Wells quadrangle.

Correlation.--Exposures previously referred to as "Walnut-Comanche Peak" crop out in Brewster County, Texas. King (1937, p. 114) assigned 50 feet of marl and thin limestone beds along the east side of the Marathon Basin to the "Walnut-Comanche Peak" but recognized lateral facies changes. Eifler (1943, p. 1626) assigned an equivalent unit to Member No. 1 of the Devils River Limestone.

Lozo and Smith (1964, p. 297) have suggested that equivalent beds be assigned to the West Nueces Formation in eastern Kinney and western Uvalde Counties, Texas.

Origin.--The unit is a shallow water, neritic to littoral, transgressive sequence.

## Del Carmen Limestone

The Del Carmen Limestone derives its name from exposures in the Sierra del Carmen of the Big Bend National Park adjacent to the map area. Maxwell and others define this unit on the basis of stratigraphic relations in the Big Bend region and use a local name. Other authors have used the term "Edwards Limestone" for these rocks.

Thickness, lithology, and fossils.--The Del Carmen Limestone is 445 feet thick at MS-3 and in conformable contact with the Telephone Canyon below and the Sue Peaks Formation above.

The limestone crops out along the Rio Grande northeast of Maravillas Creek and in the fault scarps of the Sierra del Carmen and Stairway Mountain. It is also exposed in the core of the Dove Mountain Ranch anticline.

The formation is principally a biomicrite containing chert and a various marine fauna, especially Toucasia. Of two intervals containing bioherms (fig. 6), the lower has cherty biomicrite beds flanking the bioherms whereas the upper has silty calcareous clay between the bioherms.

Figure 6. Bioherm in Del Carmen Limestone, showing arching of overlying beds and termination of bedding along flanks of bioherm. This exposure is in Coahuila across the Rio Grande from mouth of Borland Canyon. View to southeast.

Graves (1954, p. 24) measured a section 309 feet thick. To the west, Eifler measured 209 and 255 feet (1943, p. 1629). King (1937, p. 115) reported a maximum thickness of 200 feet. Both Eifler and Graves commented on the abundance of Toucasia.

Freeman (1964) estimated a thickness of about 400 feet for exposures along the Rio Grande in the Indian Wells quadrangle.

Santiago Charleston reported a thickness of 138 meters (453 feet) at Cerro el Barco, Mexico, across and downstream from the mouth of Maravillas Creek, lat 29°36'43" N., long 102°43'25" W. (letter from C. I. Smith, 16 February 1965).

The Del Carmen Limestone becomes thinner toward the Glass Mountains. It is possible that the Marathon area was uplifted during deposition of the Comanchean sediments.

Correlation.--The Del Carmen Limestone correlates with Udden's Member No. 2 of the Devils River Limestone and with the Edwards Limestone of Graves (1954). It is also correlative with the upper part of the West Nueces Formation and the McKnight Formation of the southern Edwards Plateau and southwest Texas (Lozo and Smith, 1964, p. 290).

Origin.--The Del Carmen Limestone of southern Brewster County is the product of a neritic environment. The bioherms are shallow-water reefs.

## Sue Peaks Formation

The Sue Peaks Formation derives its name from an exposure located beneath Sue Peaks (fig. 20) in the southeast part of the Big Bend National Park (fig. 2). Maxwell and others define this unit for use in the Big Bend National Park. King (1930, p. 96) and Graves (1954, p. 25) used the term "Kiamichi Formation" and Eifler (1943, p. 1627) used "Member No. 3 of the Devils River Formation" for the same rocks. The implied correlation of authors has not been demonstrated.

Thickness, lithology, and fossils.--The Sue Peaks Formation is 86 feet thick at MS-3; MS-4 includes an incomplete section. At Stairway Mountain west of the Black Gap headquarters it is 73 feet thick. The formation is easily eroded and mostly covered. It has scattered exposures of calcareous clayey siltstone. Micrite and biomicrite beds near the top contain an abundant marine fauna. The composite section (units 25 and 26, pl. 3) gives a list of fossils collected from this interval within the map area. Other fossils from the Sue Peaks Formation of the Black Gap area include *Adkinites imlayi* from an exposure near the thrust fault north of Maravillas Canyon (pl. 1, K-7) and another from the

Dove Mountain Ranch anticline (pl. 1, H-1). I also collected an Adkinites bravoensis (Böse) and a single shark vertebra from the latter locality, and a Protocardia texana from an exposure on the road along Maravillas Canyon. The Sue Peaks Formation forms a distinctive light-colored, slope-forming, vegetation-free band on scarps throughout the area (fig. 7). The change from the Del Carmen Limestone below and the Santa Elena Limestone above is abrupt, and the contacts are sharp except where obscured by talus.

Figure 7. Aerial view to the north of the northwest scarp of Big Canyon (fig. 3). The outcrop of Sue Peaks Formation is outlined by light color-bands in the middle of the scarp.

King (1930, p. 96) measured 62 feet of "Kiamichi" marl containing Gryphaea navia overlain by 21 feet of "Duck Creek" nodular marly limestone in the Glass Mountains. Young (oral communication, 1965) believed equivalents of both units, as indicated by fossils, are present at MS-4.

Eifler (1943, p. 1627) reported thicknesses of 30 to 70 feet of Member No. 3 of the Devils River Limestone, stating that the member is "strikingly fossiliferous."

Graves (1954, p. 26) measured thicknesses of 35, 46, and 57 feet in the Hood Spring quadrangle (fig. 2). He described the coquina marker bed and stated that it was overlain by massive limestone whereas 10-12 feet of calcareous siltstone separates these units in the Black Gap area. Oxytropidoceras sp., Gryphaea sp., and Enallaster texanus characterize the Sue Peaks Formation in Graves area.

Freeman (1964) mapped the "Kiamichi (?) Formation" in the Indian Wells quadrangle and estimated its thickness at about 50 feet.

Santiago Charleston reported a section of Sue Peaks Formation 24 meters (79 feet) thick at Cañon Ceferino, Coahuila, 10 miles east of the map area, lat 29°30'43" N., long 102°45'43" W. (letter from C. I. Smith, 16 February 1965).

Correlation.--The Sue Peaks Formation of the Black Gap area is correlative with the "Kiamichi" marl of other workers in Brewster County and probably includes the "Duck Creek" of King.

The Sue Peaks Formation of the Black Gap area is not equivalent to the McKnight Formation in Uvalde and Kinney Counties but rather to the lower part of the Salmon Peak Formation (letter from C. I. Smith, 29 April 1965).

Origin.--The Sue Peaks Formation represents a shallow, neritic environment, and contains clastic material derived from a nearby positive landmass.

Santa Elena Limestone

The Santa Elena Limestone was named from an exposure at the mouth of Santa Elena Canyon in the Big Bend National Park. Maxwell and others (in preparation) define the unit. The "Santa Elena Limestone" replaces the "Georgetown Limestone" of authors.

Thickness, lithology, and fossils.--The section at Santa Elena Canyon is 740 feet thick. I measured a composite section at MS-4 for a total thickness of 943 feet and Santiago Charleston reported a thickness of 305 meters (1,000 feet) at Cañon Ceferino, Coahuila, lat 29°30'43" N., long 102°45'48" W., 10 miles east of the map area (letter from C. I. Smith, 16 February 1965).

The Santa Elena Limestone of the Black Gap area is predominantly biomicrite with beds of micrite and biosparite. There are rudistid bioherms midway in the section, and chert nodules are scattered throughout the section. *Toucasia* sp. is relatively abundant. The composite section (pl. 3) lists other fossils. I found a single specimen of *Durnovarites* sp. cfr. *quadratus* Spath in talus derived from this limestone.

The Santa Elena Limestone crops out over approximately 75 percent of the Black Gap area. It constitutes the stripped structural surface of the northeast third of the map area and is the uppermost unit capping Sierra del Carmen and Stairway Mountain in the southern half of the area. It is also exposed near the intersection of the graded road to the Black Gap headquarters and State Highway 385 where it forms northwest-trending ridges. Maxwell (oral communication, 1965) found no complete section in the adjoining part of Big Bend National Park. Exposure of the basal contact of the Santa Elena Limestone is common, but the upper section at the same locality is usually eroded. I measured a complete section at MS-4 near the mouth of Drift Canyon. A complete section could also be described at the Cupola Mountain scarp but minor faulting would have to be considered.

Correlation.--Udden (1907, p. 22) estimated a total thickness of 2,000 feet of "Lower Cretaceous Limestones" in the Sierra del Carmen. Baker and Bowman (1917, p. 115) recognized strata of "Georgetown age" in the Marathon area but did not measure any clearly defined sections.

King (1937, p. 115) described "Georgetown Limestone" as "about 200 feet thick" on the west side of the Marathon Basin but gave a thickness of 175 feet on a chart (p. 20) showing formations in the Marathon area.

Eifler (1943, p. 1628) gave a thickness of 475 to 500 feet for Member No. 4 of the Devils River Limestone in the Santiago Peak quadrangle. He described the unit as massive and containing rudistids and _Gryphaea_ sp.

Graves (1954, p. 27) reported incomplete thicknesses of 385 and 393 feet and stated that the "Georgetown" is a dense to sublithographic limestone with a marly upper section.

Lozo and Smith (1964, p. 303) have redefined the "Georgetown" of Kinney and Uvalde Counties because of facies variation and proposed the term "Salmon Peak Formation." They also discussed the regional facies variations of this unit.

The Santa Elena Limestone also appears to thin toward the Marathon Basin and is added evidence for uplift during the Comanchean.

_Origin_.--The Santa Elena Limestone of the Black Gap area represents a neritic environment. It contains shallow-water reefs as evidenced by unit 29 of the composite section (pl. 3).

## Del Rio Formation

The term "Del Rio Clay" was used by Hill and Vaughan in 1898 (p. 236) for greenish laminated clay exposed near Del Rio in Val Verde County, Texas. Maxwell (oral communication, 1965) chose to apply the "Del Rio" term in the Big Bend National Park rather than "Grayson" as preferred by the Geologic Names Committee of the U. S. Geological Survey. Maxwell (oral communication, 1965) preferred to call this unit the Del Rio Formation because of geographic proximity of type locality. Lozo and Smith (1964, p. 290) concurred with Maxwell's usage.

Thickness, lithology, and fossils.--The Del Rio Formation is in many ways the most interesting stratigraphic unit in the Black Gap area. Outcrops to the west are mostly covered, as at MS-2, but scattered exposures reveal silty claystone grading to clayey siltstone with traces of gypsum and limonite pseudomorphs after pyrite. The formation is usually deeply weathered and typified by a very pale orange color. The greatest thickness of several measured is 185 feet in Big Brushy Canyon. The lower part is relatively fresh and dark gray at the thick exposure. The pale orange color results from weathering and is not original. I found no fossils in the lower part. Maxwell (oral communication, 1965) gave several thicknesses from within the Big Bend National Park. These are shown on the isopachous map (fig. 8). Santiago Charleston reported a section 3 meters (10 feet) thick from Arroyo Hormiga, Coahuila, three miles southeast of Cañon Ceferino at lat 29°27'25" N., long 102°43'25" W. (letter from C. I. Smith, 16 February 1965). This location is 10 miles east of the map area. The Del Rio is absent to the east along a line paralleling the Rio Grande (fig. 8). The isopachous map (fig. 8) suggests that during deposition of the Del Rio Formation a high existed in the area now occupied by the Rio Grande and also along a trend extending to the northwest north of and parallel with the present course of Maravillas Creek. The Del Rio thins because of relief on the depositional surface rather than from erosion or post-depositional structural activity. Termination of lower beds and overlap by upper beds is demonstrable in the Black Gap area. The western deep basin indicated by the isopachous map could have resulted from continuous downwarp or faulting along the northwest-trending, down-to-the-east fault zone shown on the geologic map (pl. 1, D-7). The structure-contour map (pl. 2) drawn on top of the Santa Elena Limestone also suggests this.

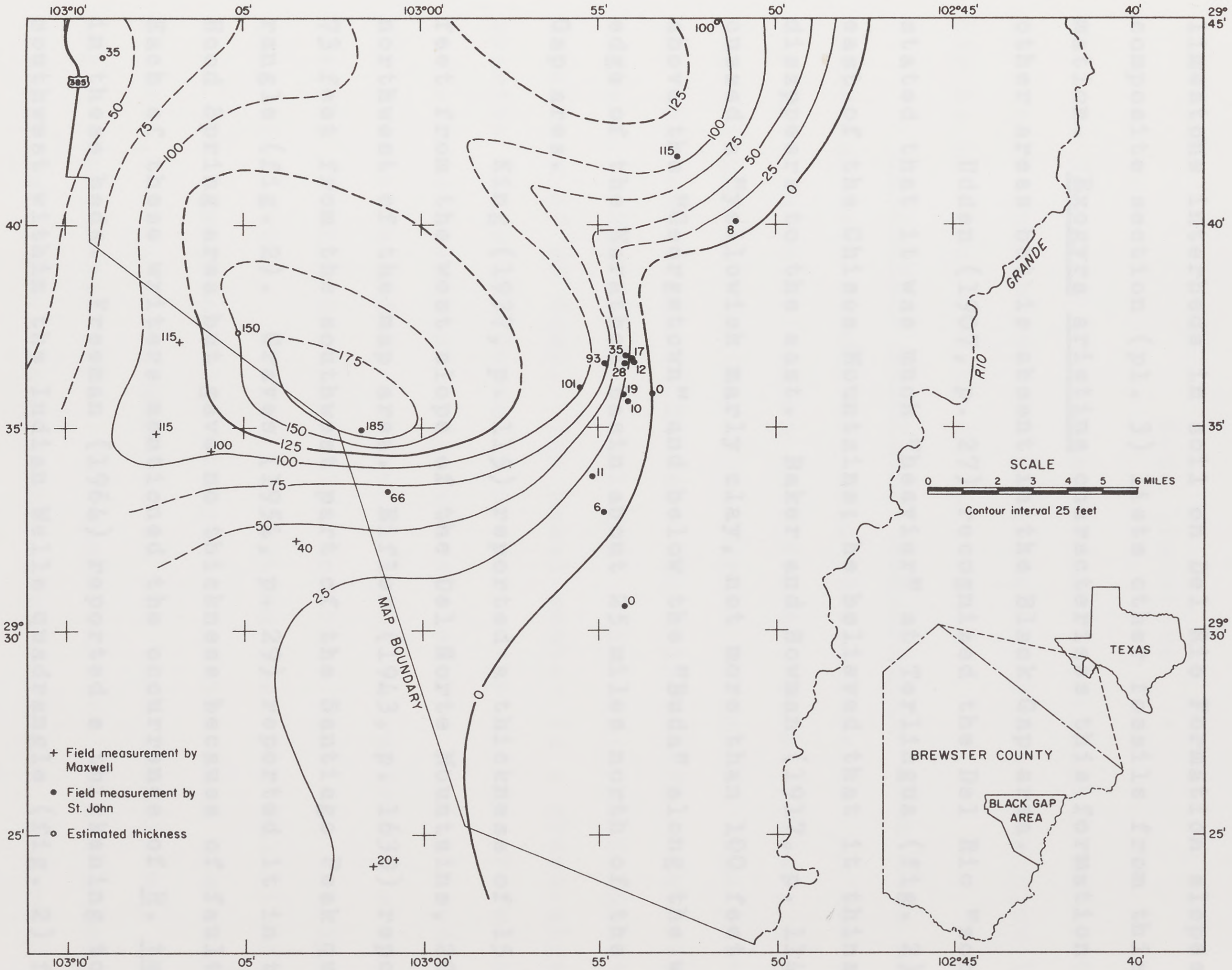



Figure 8. Isopachous map of Del Rio Formation, Black Gap area, Brewster County, Texas. Thickness in feet. Isopach dashed where inferred.

*Haplostiche texana* is the diagnostic fossil for the Del Rio Formation in the Black Gap area and appears in the limestone interbeds in soil on Del Rio Formation slopes. The composite section (pl. 3) lists other fossils from this formation. *Exogyra arietina* characterizes this formation in other areas but is absent in the Black Gap area.

Udden (1907, p. 27) recognized the Del Rio "zone" and stated that it was much "heavier" at Terlingua (fig. 2) than east of the Chisos Mountains; he believed that it thins or disappears to the east. Baker and Bowman (1917, p. 114) discussed a "yellowish marly clay, not more than 100 feet thick" above the "Georgetown" and below the "Buda" along the western edge of the Marathon Basin about 25 miles north of the Black Gap area.

King (1937, p. 115) reported a thickness of 15 or 20 feet from the west slope of the Del Norte Mountains, 20 miles northwest of the map area. Eifler (1943, p. 1630) reported 73 feet from the southwest part of the Santiago Peak quadrangle (fig. 2). Graves (1954, p. 29) reported it in the Hood Spring area but gave no thickness because of faulting. Each of these writers mentioned the occurrence of *H. texana* in these beds. Freeman (1964) reported a thickening to the southwest within the Indian Wells quadrangle (fig. 2) from 30 to 80 feet.

*Origin*.--The clayey, silty rock of the Del Rio Formation marks it as a littoral deposit.

Buda Limestone

The Buda Limestone was named by Vaughan in 1900 (p. 18) to include hard, white, limestone beds. The type locality is on Shoal Creek, Austin, Texas.

*Thickness, lithology, and fossils*.--The Buda Limestone has been subdivided into three members. In the Black Gap area, however, there is a fourth, basal member, of varying thickness. The basal member is absent in some parts of the area and is up to 22 feet thick in others. The three members overlying the basal unit maintain a uniform total thickness of 80 feet. The basal member is a green-alga biosparite and disconformably overlies the Del Rio Formation. It forms a prominent ledge above the more easily eroded Del Rio Formation and is yellowish brown to yellowish orange, thereby forming a sharp color contrast with the overlying gray biomicrite. It is interesting that the Del Rio Formation and the green-alga biosparite of the Buda Limestone thicken, thin, and pinch-out at the same localities, suggesting a similar history. The upper surface of the green-alga biosparite at MS-1 has borings that indicate subaerial exposure and therefore a disconformity. In Big Brushy Canyon (pl. 1, E-6) a coquina layer six inches to a foot thick separates the basal member from the overlying beds. This same coquina layer can be traced from the top of the green-alga biosparite into the overlying gray limestone section along the north side of the saddle on the Airplane Tank road (pl. 1, H-5). At this place the coquina layer also contains bored cobbles.

The Buda Limestone above the green-alga biosparite is divisible into three members in the western part of the map area. A massive biomicrite 10 feet thick overlies the basal biosparite and forms a prominent ledge. In some places the lower surface of this unit is burrowed (fig. 9). Above the biomicrite bed is an easily eroded clayey micrite 40 feet thick devoid of vegetation.

Figure 9. Burrowed surface of massive Buda Limestone overlying coquina zone above basal green-alga biosparite (pl. 1, H-5). View to south.

The uppermost member is a sublithographic, nodular weathering biomicrite 31 feet thick. The upper three members are yellowish gray to grayish pink and distinctive on the aerial photographs. The Buda Limestone is 80 feet thick at MS-4, but both the Del Rio Formation and the basal green-alga biosparite are missing and the Buda rests on the Santa Elena Limestone. The Buda Limestone appears thin- to medium-bedded at MS-4 and is not divisible into members.

Figure 10. Aerial view to northwest. Stillwell Mountain in upper left; Stillwell anticline extends from left to upper center. Light band on basalt-capped hill in right center is Buda Limestone, which is underlain by the crumbly Del Rio Formation. Above the Buda Limestone and below the basalt are darker flaggy beds of the lower part of the Boquillas Formation.

Budaiceras characterizes this formation and Pecten roemeri occurs near the base. Also, I collected other mollusks throughout the section.

Udden (1907, p. 27) reported thinning of the Buda in the Big Bend National Park to the east of the Chisos Mountains. King (1937, p. 115) reported about 60 feet of Buda Limestone on the west flank of the Del Norte Mountains, 20 miles northwest of the map area, where it varies from nodular to regularly bedded. Eifler (1943, p. 1632) measured 75 feet of Buda Limestone in the southwestern part of the Santiago Peak quadrangle (fig. 2). Graves also reported three members within the Buda Limestone. Freeman (1964) also mentioned the three members within the Indian Wells quadrangle (fig. 2) and reported thickening to the west from 78 to 90 feet. Santiago Charleston reported a thickness of 30 meters (98 feet) in Arroyo Hormiga, Coahuila, lat 29°27' 25" N., long 102°43'25" W., 7 miles west of the map area (letter from C. I. Smith, 16 February 1965).

Correlation.--Lozo and Smith (1964, p. 290) pointed out that workers have demonstrated lithologic continuity throughout southwest Texas.

Origin.--The basal green-alga biosparite is a marginal basin facies, and the abundance of sparry calcite suggests a relatively high-energy environment. A disconformity separates the basal member of the Buda from the overlying section, which represents a deeper water, low-energy environment. The disconformity is indicated by a coquina zone containing bored cobbles.

## Gulfian Series (Terlingua Group)

In the Black Gap area the Gulfian Series is represented by the Boquillas and Pen Formations of the Terlingua Group.

Udden used the term "Terlingua beds" in 1907 (p. 33) for exposures along Terlingua Creek (fig. 3), Brewster County, Texas, 35 miles west of Black Gap. He defined the Terlingua as chalky, marly clay that grades downward into the Boquillas flags and upward into the Rattlesnake beds (Aguja Formation). Udden included those units he believed equivalent to the Austin chalk and Taylor marl of central Texas.

Maxwell and others (in preparation) raise the term "Terlingua" to group status to include all the strata from the top of the Buda Limestone to the base of the Aguja Formation (Udden's Rattlesnake beds). The Cretaceous formations above the Terlingua Group in the Big Bend National Park are not present in the map area.

### Boquillas Formation

Udden (1907, p. 29) originally used the term "Boquillas Flags" for rocks on Tornillo Creek, Chisos Mountain quadrangle (fig. 2), Brewster County, Texas. Udden's Boquillas included a lower, thin-bedded, fossiliferous, flaggy limestone and an overlying chalky limestone.

Eifler (1943, p. 1632) redefined the "Boquillas Limestone" in the Santiago Peak quadrangle to include limestone beds above the Buda Limestone and below the top part of the Inoceramus undulato-plicatus zone. Maxwell and others (in preparation) define the Boquillas Formation to include the flaggy, marly units. Although Eifler and Maxwell mapped the same beds as "Boquillas," their definitions are different. Maxwell subdivided the Boquillas Formation into the Ernst Member, which includes the lower flaggy beds, and the San Vicente Member, which includes the chalky limestone and calcareous shale above the flaggy beds and below the gypsiferous Pen Clay.

Figure 11. Ammonite-laden [Dunveganoceras (?)] slab of flaggy limestone of Ernst Member of the Boquillas Formation. Exposure along creek bottom in Heath Canyon (pl. 1, J-9).

I do not subdivide this unit on the geologic map (pl. 1) but lump it as the Boquillas Formation. MS-1 and MS-5 together give a composite thickness of 551 feet.

The Boquillas Formation crops out in the Black Gap area within the northwest-trending structural and topographic low extending from Stillwell, Heath, and Horse Canyons northwest through the Black Gap headquarters to State Highway 385. The broadest area of outcrop is between Black Gap and Maravillas Canyon.

Erosional remnants of the Boquillas Formation crop out at Cupola Mountain, Black Mountain, and west of Dove Mountain. Other exposures are in the low hills between Big Brushy Canyon (pl. 1, E-7) and the Stillwell ranchhouse and along the gravel-covered scarp west of Bear Creek west of the Dove Mountain Ranch anticline (pl. 1, E-2).

Ernst Member.--Maxwell and others (in preparation) name the Ernst Member of the Boquillas Formation for outcrops near Ernst Tank on the west side of the Sierra del Carmen. They define the Ernst as the basal member of the Boquillas Formation.

I measured 277 feet of silty, thin- to medium-bedded, flaggy, brown to gray, micrite and biomicrite beds at MS-1. A sharp lithologic change marks the contact with the underlying Buda Formation and a topographic and lithologic change marks the gradational contact with the overlying San Vicente Member. Previous workers suggested that sinkholes in the Buda Formation containing flaggy Ernst beds are evidence of unconformity. These same features occur in the Black Gap area (fig. 12) but I am convinced these karst features are younger than the flaggy limestone beds. The flaggy beds in the sinkholes are brecciated indicating collapse after lithification. Other than the sharp lithologic change from massive, sublithographic limestone of the Buda to the overlying silty, thin-bedded limestone of the Ernst Member, there is no physical evidence to suggest an unconformity between these units in the Black Gap area.

Figure 12. View south through Heath Creek, showing a sinkhole in Buda Limestone on left bank filled with flaggy beds of the Ernst Member, and thin flaggy beds along the right bank.

Fragments of Inoceramus labiatus are common in the Ernst Member, especially in the upper part. Other fossils are present (pl. 3) but not abundant.

Freeman (1964) described about 100 feet of "Boquillas Flags," which belong to the Ernst Member.

Maxwell correlates the Ernst Member with Eagle Ford Shale of central Texas.

The Ernst Member, as mapped in the Big Bend National Park and Black Gap area, includes the lower part of Udden's original Boquillas Formation and the lower part of Eifler's Boquillas Limestone. King (1937, p. 116) tentatively correlated equivalent beds near the Del Norte Mountains with the Eagle Ford Formation of central Texas.

The occurrence of well-rounded and sorted quartz silt and sand grains in the lower beds indicate deposition near a shoreline. Lack of coarse sand, gravel, or coquina layers plus well defined bedding suggests a slow advance or retreat of the shoreline associated with relatively low-energy wave action.

San Vicente Member.--Maxwell and others (in preparation) named the San Vicente Member for exposures near the abandoned village of San Vicente in the Big Bend National Park.

Composite thickness of the San Vicente Member in the

Black Gap area is 274 feet. This member differs from the underlying Ernst Member: it has thicker beds and weathers yellow gray. The lower 125 feet is composed of thin- to medium-bedded nodular micrite containing I. labiatus. Above this micrite layer is a covered interval 66 feet thick with scattered exposures of easily eroded calcareous clay. Without exposure of the associated micrite beds this clay interval could not be differentiated from the younger Pen Clay. I found no fossils in the clay interval. A clayey micrite 83 feet thick overlies the clay and is gradational into the overlying Pen Clay. The contact between the San Vicente Member and the overlying Pen Clay is drawn at the top of the uppermost limestone bed. Inoceramus sp. is common throughout this micrite, and a concentration of Inoceramus undulato-plicatus occurs 35-50 feet above the base of the San Vicente Member. This is the Inoceramus undulato-plicatus zone (Maxwell and others, in preparation; and Eifler, 1943, p. 1634). Graves (1954, p. 30) reported an exposure in the Hood Spring quadrangle (fig. 2) of chalky limestone 15 feet thick, which he called "Terlingua Formation." The strata he described belong not in the Pen Clay of this report but in the San Vicente Member.

Maxwell and others (in preparation) correlate the San Vicente Member with the Austin Chalk of central Texas.

They include Udden's lower flagstone member of the Boquillas Formation and the lower flagstone member and middle marl member of Udden's Terlingua Formation.

The upper and lower micrite beds containing Inoceramus sp. are probably a result of deposition in water deeper than that which received the sediments of the Ernst Member. As the sea transgressed, the sea bottom became deeper, the shoreline was farther from the area of deposition and the low-energy environment continued. The calcareous clay suggests a seaward retreat of the shoreline and reworking of the newly deposited calcareous sediments with a resulting transport of clay-size particles into clear water. The sudden abundance of clay particles would have muddied the water and probably killed the fauna, so that fossils are lacking. Re-establishment of the transgressive movement cleared the water and the fauna flourished again, leaving the abundant fossils of the Inoceramus undulato-plicatus zone.

## Pen Clay

Maxwell and others (in preparation) name the Pen Clay for exposures near Chisos Pen north of the Chisos Mountains (fig. 2) in the Big Bend National Park. The Pen Clay thus defined replaces the upper clay member of Udden's "Terlingua clay."

_Thickness_, _lithology_, _and_ _fossils_.--The Pen Clay crops out only in the basalt-capped center part of the map area. The pre-basalt paleogeologic map (fig. 13) outlines the outcrop limits. No Cretaceous strata younger than Pen Clay remain in the Black Gap area. The highly resistant basalt cover has protected the easily eroded Pen Clay; otherwise it too would have been removed long ago. At MS-5 only 50 feet of Pen Clay is present beneath the basalt. From outcrop width, estimated dip, and the topographic map, I calculated a thickness of 500 feet west of the Black Gap syncline and immediately north of the Black Gap headquarters. Udden estimated a thickness of 1,280 feet near Chisos Pen in the Big Bend National Park including, at the base, 100 feet equivalent to the upper part of the San Vicente Member of the Black Gap area.

Eifler (1943, p. 1634) reported approximately 200 feet of gray marl overlying the Boquillas Formation along the west side of YE Mesa 12 miles northwest of the map area. The gray marl probably is correlative with the Pen Clay.

The Pen Clay is calcareous and gypsiferous in the Black Gap area. _Inoceramus_ _grandis_ occurs near Bee Cave Tank three miles northwest of the Black Gap headquarters, and _Inoceramus_ prisms are not uncommon in the Pen Clay.

_Correlation_.--The Pen Clay consists of strata formerly termed "Terlingua (restricted)" in the Big Bend area. Maxwell and others (in preparation) correlate it with the upper chalk member of the Austin Chalk near Austin, Texas.

Origin.--Although younger Cretaceous rocks are missing in the Black Gap area, the Pen Clay is overlain by the Aguja Formation in the Big Bend National Park. The clay itself suggests sediments laid down by a regressing sea. Some animals lived in this environment but not many died and were preserved in it. The occurrence of gypsum in the clay suggests shallow-water evaporitic conditions.

## TERTIARY ROCKS

### Extrusive Rocks

Tertiary extrusive basalt covers a large area near the Black Gap headquarters in the central part of the map area (pl. 1). This outcrop is in the major northwest-trending graben between the Sierra del Carmen and the Cupola Mountain area (pl. 1).

A conglomerate containing chert similar to that found in the Paleozoic rocks of the Marathon Basin occurs beneath the basalt in the Black Gap area (Wilson, 1951, p. 68).

The pre-basalt paleogeologic map (fig. 13) indicates that the basalt extrusion followed down-to-the-west faulting

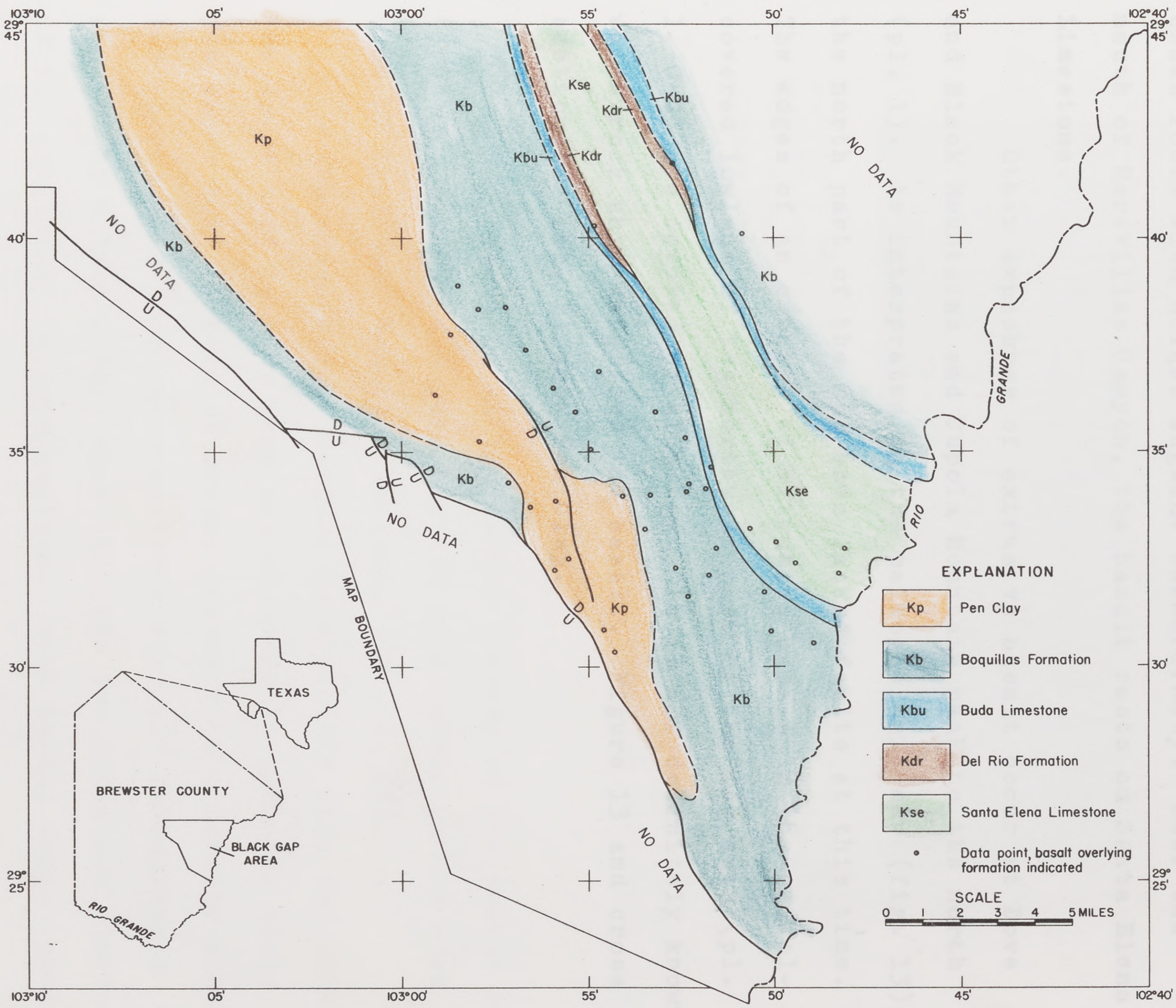



Figure 13. Pre-basalt geology of Black Gap area, Brewster County, Texas.

which brought Pen Clay to the west into contact with Boquillas Formation to the east. The basalt overlies Cretaceous rocks with slight angular unconformity. Near the mouth of Maravillas Canyon, the basalt rests on Santa Elena Limestone.

Other exposures of extrusive basalt occur at Dove and Black Mountains and Cupola Mountain peak to the north (pl. 1). As interpreted on the paleogeologic map (fig. 13), the north part of the map area lacked faults at this time. The edges of an outcrop of extrusive basalt in the gravel-covered lowland of the northwest part of the map area (pl. 1, C-2) are covered by alluvium. It is not definitely known which rock unit underlies the basalt. Figure 13 and cross section AA' (pl. 1) show Pen Clay.

Figure 14. Westward aerial view of Black Mountain with Santiago Peak (right) and YE Mesa on skyline at right of picture; Persimmon Gap and Nine Point Mesa are on skyline at left side of picture. The recessed slope of Del Rio Formation separates the Santa Elena Limestone below and Buda Limestone above; Ernst Member of Boquillas Formation is obscured by talus from overlying Tertiary extrusive basalt.

The thickness of the basalt depends on the amount of erosion. Maximum thickness of 450 feet occurs on the east side of Stillwell Mountain (Wilson, 1951, p. 68).

The thick basalt section is divisible into two units. The lower unit is dark gray and weathers to a smooth slope. The upper unit is reddish brown, weathers into massive angular blocks, and forms near-vertical scarps. Petrographic studies by Wilson (1951) show that the two units are similar, if not identical, in thin-section. Both basalt units consist of several flows separated by vesicular zones. The vesicles are elongated horizontally and filled with chalcedony or calcite. Both units are non-porphyritic and fine-grained. Both units exhibit flow structure and each is composed of plagioclase (labradorite), titaniferous augite, olivine, iddingsite, and minor accessory minerals.

No one has attempted to date the series of flows in these outcrops.

Pinto Tank, on the Dove Mountain Ranch, is the site of an intrusive plug in the core of a collapse feature. Olivine basalt has extruded along the faults bordering the collapse area (fig. 15). The olivine basalt is holocrystalline, non-porphyritic, and trachytoid. The rock was originally composed of 67 percent plagioclase, 31 percent olivine, and 2 percent magnetite. The olivine has altered to iddingsite so that the rock now contains 24 percent iddingsite pseudomorphs after olivine and 7 percent olivine. Also, the plagioclase is partly altered to sericite.

Volcanic activity resulting in the extrusion of the basalt occurred prior to much of the great folding and faulting now evident. A good example of this is Black Gap syncline (fig. 16) where the basalt forms the upper surface of this feature.

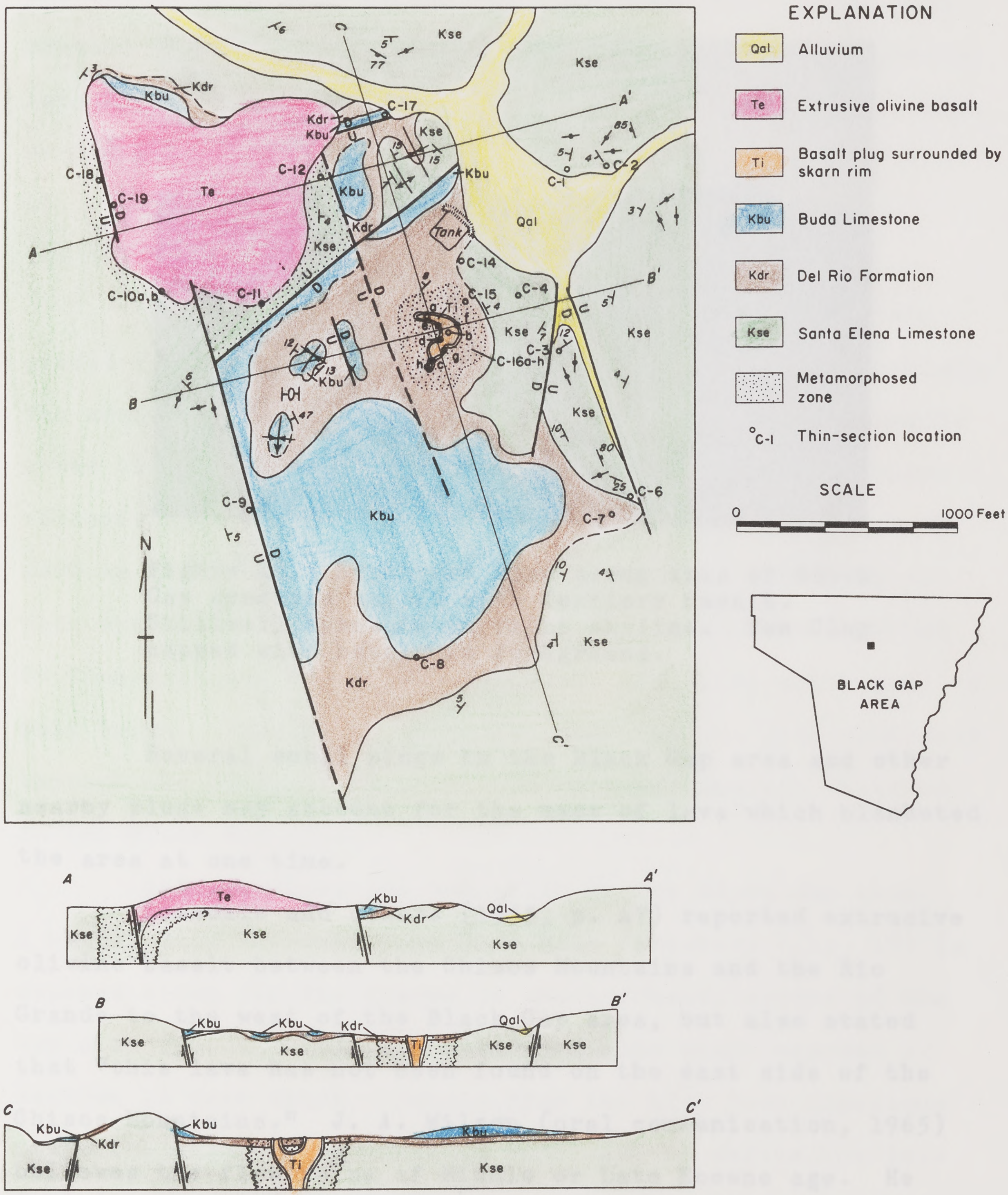



Figure 15. Sketch map of Pinto Tank vicinity of Dove Mountain Ranch, Black Gap area, Brewster County, Texas.

Figure 16. Northwest view along axis of Black Gap syncline capped with Tertiary basalt. Stillwell Mountain on right skyline. Pen Clay capped with basalt in foreground.

Several small plugs in the Black Gap area and other nearby plugs may account for the mass of lava which blanketed the area at one time.

Lonsdale and others (1955, p. 47) reported extrusive olivine basalt between the Chisos Mountains and the Rio Grande to the west of the Black Gap area, but also stated that "this lava has not been found on the east side of the Chisos Mountains." J. A. Wilson (oral communication, 1965) believes the flow to be of Middle or Late Eocene age. He has collected Middle Eocene fauna from the continental sedimentary rocks beneath the basalt. J. A. Wilson also reports Late Eocene fauna from tuffs overlying the basalt at Castilon on the west side of the Chisos Mountains.

## Intrusive Rocks

Agglomerate.--An agglomerate is exposed beside the graded road two miles northwest of the Black Gap headquarters. The area of exposure is small and an extensive gravel mantle masks the true dimensions. This agglomerate probably marks a volcanic vent. The agglomerate contains basalt boulders as much as four feet in diameter. The basalt is dark gray to pale brown, vesicular and scoriaceous. The matrix material is fine-grained, extremely weathered, and light olive gray to pale brown. Pebbles of limestone and clay are also scattered through the matrix. This was the only agglomerate observed in the Black Gap area.

Sills.--There are two sills in the Black Gap area. A basalt sill intruded into Glen Rose Limestone (fig. 17) is exposed along the Rio Grande in the northeast corner of the map area (pl. 1, P-3). An abandoned mine shaft exposes a section 12 feet thick. Debris from the Glen Rose Limestone masks the outcrop and makes it difficult to define the lateral limits. The basalt is non-porphyritic, fine-grained holocrystalline, and is composed of 49 percent plagioclase with 13 percent biotite, 12 percent titanaugite, 9 percent amphibole, 6 percent iddingsite, 5 percent augite, 4 percent magnetite, and 2 percent analcime plus traces of apatite, calcite, and leucoxene (Appendix, petrographic descriptions, BTx-S-8).

Figure 17. Westward view of basalt sill within Glen Rose Limestone (pl. 1, P-3).

An analcime gabbro sill (fig. 18) intruded into the Ernst Member extends over much of the west-central part of the map area. It is exposed in the low hills west and northwest of the Black Gap headquarters, where it is 112 feet thick. It is also exposed in Big Brushy Canyon, in the valley behind Guliher's house (pl. 1, D-5), and in the low gravel-capped hills five miles west of Stillwell Mountain. The sill is also exposed on the sides of Stillwell Mountain and beside the road just east of Black Gap. The sill is deeply weathered wherever exposed and has a dark reddish-brown mottled appearance. It weathers into subspheroidal blocks. Petrographic examination reveals that it is fine- to medium-holocrystalline and non-porphyritic. The rock is 76 percent plagioclase, 12 percent analcime, 6 percent aegirine-augite, and 5 percent iron oxide (Appendix, petrographic descriptions, BTx-M1-6). Lesser amounts of accessory minerals are present. The analcime is late- or post-magmatic and fills void spaces in the feldspar. The aegirine-augite crystals are zoned.

Figure 18. Northward view of analcime gabbro sill in Ernst Member of Boquillas Formation at MS-1 showing subspheroidal weathering.

<u>Dikes</u>.--Along the fault trace on the eastern edge of Dove Mountain Ranch anticline are several exposures of igneous rock. Petrographic examination indicates a fine- to medium-holocrystalline, porphyritic olivine basalt. Flow structure is manifest and euhedral olivine crystals have altered completely to iddingsite (Appendix, petrographic descriptions, BTx-S-10a and 10b). The rock also contains abundant augite (10b). Samples from an unusual rock (10a) at this same location reveal an intrusive basalt breccia. The rock is merocrystalline and porphyritic. Micro-xenoliths

or volcanic-rock fragments up to 6.5 mm long are basalt and exhibit vesicles and oriented plagioclase laths. This is the only dike that I found in the Black Gap area.

Plugs.--Numerous small plugs seldom exceeding 50 feet in diameter occur in the Black Gap area. The plugs are concentrated west and south from Dove Mountain.

A basalt plug (pl. 1, H-2) east of the Dove Mountain Ranch anticline is composed of holocrystalline, porphyritic, and trachytic rock. The basalt is 74 percent plagioclase. The plagioclase crystals are rounded and partially resorbed suggesting crystallization at depth followed by intrusion with temperature-pressure changes. The rock also has partly resorbed augite phenocrysts and augite with leucoxene coronas surrounded by hematite rims.

West of Cupola Mountain peak (p. 1, K-3) is a plug exposing unusually fresh rock. The rock is holocrystalline, non-porphyritic, fine- to medium-grained basalt. It is composed of 62 percent plagioclase plus pyroxene, iddingsite, and magnetite. Iddingsite has completely replaced olivine. The pyroxene in this plug is not the same as that in the sills mentioned earlier; the difference suggests different sources or at least different times of intrusion.

At Pinto Tank (fig. 15), Dove Mountain Ranch, is a basalt plug associated with a collapse feature. Fourteen samples from this location were thin-sectioned and studied. The magma of the plug was probably very hot and "wet." The plug is in contact at the surface with the Buda Limestone and the Del Rio Formation. Surrounding the plug is a resistant rim of skarn resulting from metamorphism. The resistant rim is about ten feet wide and surrounded by marble for a distance of 50 feet. No trace of fossils or bedding appear in the marble which consists of equant grains averaging three mm diameter. The skarn rim contains an abundance of chalcedony and hydro-grossularite garnet (Barker, oral communication, 1965) plus significant percentages of calcite, epidote, and aegirine-augite. The basalt plug is porphyritic with a cryptocrystalline matrix composing 42 percent of the rock. X-ray analysis indicates the matrix is composed of analcime, plagioclase, pyroxene, biotite, and amphibole.

Associated with this plug is basalt extruded along a fault trace. Perhaps at some unknown depth the intrusive plug left a void, which resulted in the "collapse" of the overlying sedimentary rock along faults. Basalt later passed through these fault zones, extruding on the surface and metamorphosing the Santa Elena Limestone on either side of the fault trace for a distance of five to ten feet.

Southeast of Dove Mountain and northeast from Black Mountain is a circular rim of intrusive basalt (pl. 1, K-1) several hundred feet in diameter. The surrounding Santa Elena Limestone is metamorphosed for a distance of 10-20 feet. The limestone around the plug does not seem to be tilted to any degree. The crater is breached to the northwest and the interior is covered with alluvium. King (1937, p. 117) suggested that this feature may be a recent explosion crater. Probably, it is a remnant of a vent and the rim represents more resistant rock near the contact zone.

### Summary of Tertiary Rocks

The Tertiary igneous and volcanic rocks of the Black Gap area are part of an alkalic kindred. Differences in mineral composition are not so great as to require different sources; such differences as exist could be a result of preintrusive differentiation.

## TERTIARY-QUATERNARY BOLSON FILL

A partially dissected bolson fill is located on the Adams Ranch in the extreme south end of the map area. Two miles south of the turnoff to Stillwell Canyon terrace levels are cut into deposits of pinkish orange silty clay. The clay extends south to the Rio Grande. No bones have been found in the bolson deposits, however, an extensive search was not made. Possibly the bolson was deposited during both

Quaternary and Tertiary periods.

A fault block of Santa Elena Limestone dammed the ancestral Rio Grande forming a lake. Sediments in the lake, which exceed 150 feet in thickness, filled to the level represented by the upper surface of the damming fault block. Waters of the Rio Grande incised the fault block, lowered the base level, and subsequent downcutting has resulted in the terrace levels preserved today.

The bolson fill is predominantly silty clay with interbedded gravel. The gravel layers are two to five feet thick and are composed of coarse sand, pebbles, and cobbles of limestone, igneous, and volcanic rock. No chert or novaculite was noted in these gravels.

The bolson extends south into Mexico an undetermined distance. Terrace levels are visible on the Mexican side of the river which are not present on the Texas side. A detailed study of the bolson on both sides of the river would be interesting, however such is beyond the scope of this report.

## QUATERNARY ROCKS YOUNGER THAN BOLSON FILL

### Older Gravel

Certain gravels in the Black Gap area are deposits from older erosion cycles and can be mapped separately. Most of these older gravels are composed principally of igneous rocks uncommon in later deposits.

A mile south of Maravillas Creek along the dirt road from State Highway 385 to the Black Gap headquarters is an extensive, topographically high, gravel deposit. The gravel consists of pebbles and cobbles of white, black, green, and red chert from the Marathon region. Abundant igneous rock types including cobbles of agate are also present. Similar gravel deposits occur to the west along the edge of the mountain range bordering the Big Bend National Park. Maxwell and others (in press) mapped these deposits as "older gravel." I have extended this unit into the Black Gap area.

There is another gravel deposit, not thick enough to warrant mapping, near Pinto Tank, site of the previously described collapse feature. The surface is littered with cobbles of quartz-sanidine welded tuff. The source of these cobbles is not known but they are not from the Black Gap area.

At the mouth of Big Canyon, in the northeast corner of the map area, is a remnant of an older gravel composed entirely of limestone cobbles and boulders cemented with calcite. The remnant exhibits massive, torrential crossbedding and is not related to the surrounding uncemented terrace gravel and alluvium.

## Pediment Gravel and Undifferentiated Gravel

Pediment gravels of mappable extent occur along Maravillas Canyon near the Rio Grande and along the Rio Grande northeast from the mouth of Maravillas Creek. These gravels contain subangular to rounded cobbles and pebbles of locally derived limestone plus the colored cherts indicative of Marathon Basin Paleozoic rocks. I mapped different levels where identifiable. In some areas these gravels are cemented with caliche.

About 100 square miles of the northwest corner of the map area is mantled by gravel. The gravel is composed mainly of limestone pebbles and cobbles plus a significant amount of chert from Paleozoic rocks of the Marathon Basin and a few pebbles of igneous rock. The gravel deposits appear to be nowhere more than 30 feet thick and the entire gravel mantle may have been deposited by a meandering Maravillas Creek. For this reason I have mapped the deposit in this area as "undifferentiated gravel" and not as bolson fill.

## Landslide Material

The term "landslide material" is virtually self-explanatory and, as expected, the material occurs on the slopes beneath fault and erosion scarps. The landslide deposits, however, present a problem of presentation on the geologic map (pl. 1), for example on the southwest side of Stillwell Canyon (K-10). To the north, the landslide deposit covers the fault trace and laps onto the Santa Elena Limestone, whereas to the south the fault marks separation of the limestone beds from the landslide material. This is a function of the dip of the fault plane. Where the dip is inclined from the vertical, the fault trace is partly covered by debris. Where the dip is nearly vertical and the scarp has not yet retreated through erosion, the fault trace must separate the limestone from the landslide material whatever the thickness of the material.

## Alluvium

Unconsolidated, relatively small-grained clastic material is deposited along the banks of the Rio Grande and Maravillas Creek plus innumerable small drainage creeks.

Two levels are discernible along Maravillas Creek between State Highway 385 and the Santa Elena Limestone scarp east of the Stillwell Ranch. Considering the vast amounts of runoff handled by this creek, however, and the volume of coarse material that can be moved in a short time by such torrential flooding, I have not differentiated these alluvial levels. They may not be there tomorrow.

## R E G I O N A L   T E C T O N I C   F E A T U R E S

The Paleozoic Ouachita structural belt (fig. 19) trends northeastward across the Big Bend region.

The Diablo Platform to the northwest (fig. 19) was intermittently positive from Precambrian through early Mesozoic and formed a buttress to the Ouachita orogen (Flawn and others, 1961, p. 57).

South of the Big Bend area lies the Coahuila Platform. It is believed to have been a positive feature by late Jurassic and to have been flanked by submerged negative areas at least into early Cretaceous (Murray, 1961, p. 133). The western negative area was the Mexican Geosyncline, a deep sediment-catching basin which later developed into the folded, uplifted Sierra Madre Oriental. The eastern negative area is now referred to as the Sabinas Basin and contains a great thickness of Jurassic and Cretaceous strata.

The Marathon Dome lies to the north and northwest of the Black Gap area.

Southeast of the Marathon Basin is the Serrania del Burro, extending southeast into Mexico (Murray, 1961, p. 131). Structurally, it is an anticlinorium with a northwest-trending axis and is asymmetrical to the northeast. Metamorphosed pre-Mesozoic rocks in its core possibly represent

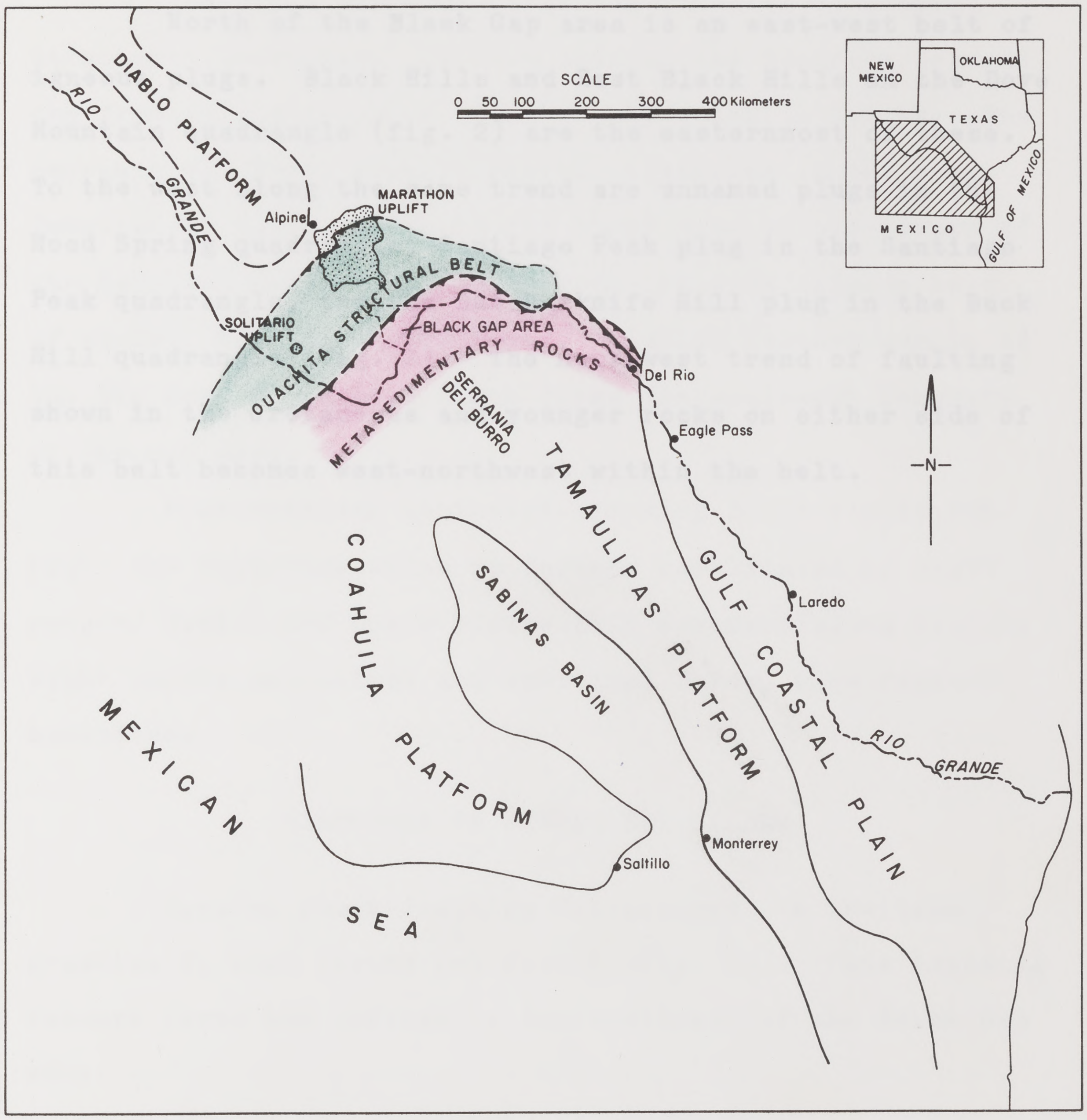



Figure 19. Regional tectonic features of southwest Texas and northeast Mexico (after Humphrey, 1956, p. 31, and Flawn and others, 1961, p. 101).

basement relief of thousands of feet. Jurassic and Cretaceous rocks overlie the metamorphic rocks.

North of the Black Gap area is an east-west belt of igneous plugs. Black Hills and East Black Hills on the Dove Mountain quadrangle (fig. 2) are the easternmost of these. To the west along the same trend are unnamed plugs in the Hood Spring quadrangle, Santiago Peak plug in the Santiago Peak quadrangle, and the Butcherknife Hill plug in the Buck Hill quadrangle (fig. 2). The northwest trend of faulting shown in the Cretaceous and younger rocks on either side of this belt becomes west-northwest within the belt.

# S T R U C T U R E

The Black Gap area is at the junction of several structural provinces. It lies astride the boundary between the frontal and interior zones of the Ouachita System. The Serrania del Burro arch of Mexico terminates in the area. Immediately to the north is the hinge line of the upwarp of the Marathon Dome marked by an east-trending igneous belt of vents. The block- and reverse-faulted eastern margin of the Big Bend structural block forms the southwest boundary of the map area.

Near-vertical northwest-trending fault blocks dominate the structure which is further complicated by small reverse faults and minor strike-slip movement along faults, tight narrow anticlinal and synclinal folds, plus faulted monoclines.

## STRUCTURE OF SIERRA DEL CARMEN

Massive block-faulting has occurred in the topographically high Sierra del Carmen (fig. 20). This imposing feature forms the skyline to the southwest of the Black Gap area.

Most of the fault blocks are folded and tilted (pl. 2) to the southwest (cross-sections C and D, pl. 1).

Figure 20. Aerial view to southwest of the block-faulted Sierra del Carmen. Sue Peaks, to the left, and Stuart Peak, in the middle, are on the skyline. Major faults are at the foot of each scarp visible in the picture.

Near Persimmon Gap are several reverse faults overthrust to the southwest. The reverse faults extend south as far as Dog Canyon. A monoclinal fold occurs farther south along the same trend, but has reversed the sense of movement and is down-to-the-northeast.

## Block Faults

Numerous faults trending approximately N. 20° W. with hanging wall down to the east form a horst complex of difficult access terrain in the southern part of the Sierra del Carmen. The dip of these faults appears to range from vertical by less than 10°.

A seemingly anomalous feature in the Sierra del Carmen is the bending of the N. 20° W. fault traces to approximately N. 75° W. This is readily observed west of Red House Tank, at the north end of Stairway Mountain, and at the entrance to Big Brushy Canyon.

Throw within the Black Gap area is at a maximum in the Sierra del Carmen. The major faults in this area average 1,700-2,000 feet throw with a maximum of approximately 2,300 feet. The throw is graphically illustrated on the cross sections (pl. 1) and on the structure-contour map (pl. 2) with the inset indicating relative displacement. That throw changes abruptly along strike is illustrated by a fault block on the east flank of Stairway Mountain three miles south of the Black Gap headquarters along the road to La Linda (fig. 21).

Figure 21. Aerial view to the southwest of the face of Stairway Mountain (pl. 1, G-8), showing abrupt increase of throw from left to right along the fault block in front.

The most prominent fault in the Sierra del Carmen extends from the northeast side of Stairway Mountain south to the Rio Grande along the southwest side of Stillwell Canyon. The fault is not the one with the most throw but it marks the eastern edge of the Sierra del Carmen and forms an imposing scarp overlooking the topographically low Black Gap graben.

## Big Brushy Canyon Graben

Big Brushy Canyon (pl. 1, D-7) is in a graben exposing rocks of the Del Rio, Buda, and Boquillas formations. Flanking the graben are structurally and topographically high blocks of Santa Elena Limestone. The isopachous map of the Del Rio Formation (fig. 8) indicates maximum thickness in the graben area and suggests downwarp of this area during deposition of the Del Rio Formation.

The uplifted block of Santa Elena Limestone on the east flank of the graben is domed and reveals a sharp roll-over into the fault bordering the graben (fig. 22). The roll-over may be the result of drag-folding or more probably draping over faulted basement blocks.

Figure 22. Southeastward aerial view with Big Brushy Canyon in foreground and Pico Etero on skyline, showing roll-over into Big Brushy Canyon of the stripped structural surface of Santa Elena Limestone in center of photograph.

The northwest-trending fault forming the southwest edge of the graben is nearly vertical. A slab of Del Rio-Buda is draped across the fault scarp west of Rainbow Tank (figs. 23 and 24d). Throw along each side of the graben is approximately 600 feet.

Figure 23. Aerial view to southwest of Del Rio Formation-Buda Limestone draped over near-vertical fault scarp of Santa Elena Limestone. Big Brushy Canyon is to the left; Big Brushy monocline is in upper right. Road in right center leads to barite deposit.

Sanford (1959, p. 46) demonstrated curvature of fault planes and inferred that a decrease upward in thickness of units involved results in progressively greater curvature and lower dip at the upper surface. The following sketch showing development of the Big Brushy Canyon graben supports Sanford's theory:

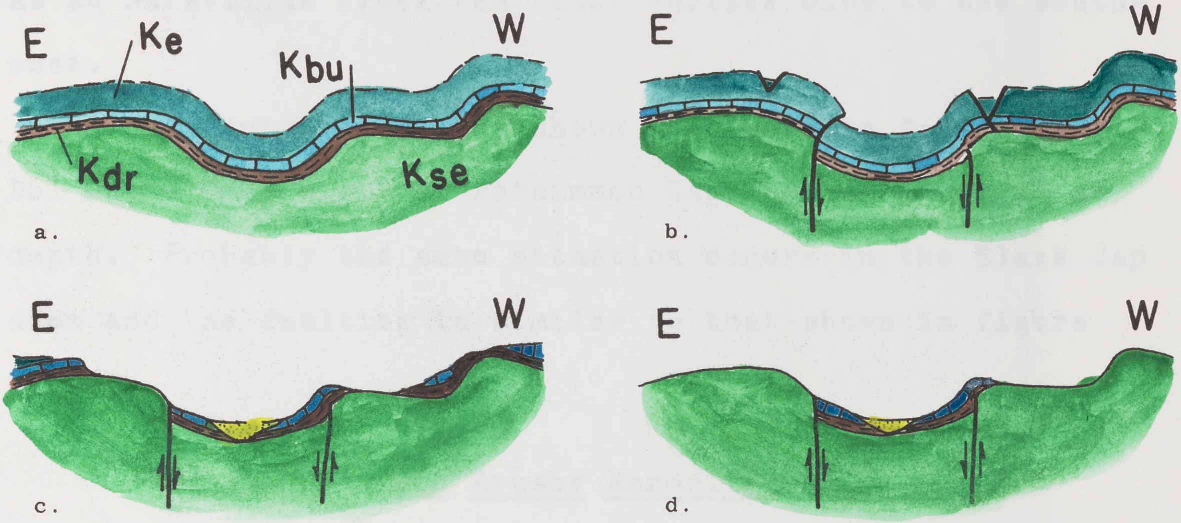



Figure 24. Probable progressive development of Big Brushy Canyon graben, section above Ernst Member and below Santa Elena Limestone not shown: a) original folding across Big Brushy Canyon, b) downfaulting of graben block, c) erosion leaving remnant poised over western fault trace, d) gravity movement of remnant over fault trace plus erosion resulting in present outcrop pattern.

## Reverse Faults

Northwest-trending reverse faults near Persimmon Gap have brought Paleozoic rock (Ordovician to Pennsylvanian) to the northeast into contact with Cretaceous (Glen Rose Limestone) rocks to the southwest. Six miles north of Persimmon Gap where State Highway 385 crosses Maravillas Creek is another area of reverse-faulting where only Cretaceous rocks are exposed. Strike of the reverse faults are the same at both locations but sense of movement is reversed. At

Persimmon Gap the fault surface dips to the northeast whereas at Maravillas Creek the fault surface dips to the southwest.

Everett (1964) has shown that reverse faults near Del Norte Gap, north of Persimmon Gap, become vertical at depth. Probably the same situation occurs in the Black Gap area and the faulting is similar to that shown in figure 24b.

## Big Brushy Monocline

A northwest-trending monocline down-to-the-east two miles west of Big Brushy Canyon is on trend with the Persimmon Gap reverse faults, but the sense of movement is reversed. The monocline begins just south of Dog Canyon and extends south to the fault scarp north of Stuart Peak (fig. 25). Maximum structural relief along the monocline is 500 feet. The axis of the monocline has the same strike as the major fault trend, N. 20° W.

A major northwest-trending fault terminates the monocline to the south, proving that the folding is older than the faulting.

Figure 25. Aerial view to southeast along crest of Big Brushy monocline, showing trace of bedding in Santa Elena Limestone. A major fault extends from the lower right along the valley to the upper left.

The monoclinal crest forms a topographic high from which much of the area to the north and northeast can be seen (fig. 26).

## STRUCTURE OF THE BLACK GAP GRABEN

The northwest-trending Black Gap graben extends from the Rio Grande northwest to State Highway 385. It is bounded on the southwest by the Sierra del Carmen horst complex and on the northeast by the fault scarp marking the Cupola Dome.

Figure 26. Panoramic view to the north and northeast from the southern crest of Big Brushy monocline, showing monoclinal extension to northwest along left side. Upper parts of Dove Mountain, Black Mountain, and Stillwell Mountain extend above cloud-filled lowland to the north and east.

It encompasses an area containing normal and near-vertical northwest-trending faults, the narrow and tight Stillwell anticline plus monoclinal and synclinal folds associated with faults, plus a reverse fault and a complex collapse structure. Faulting of the graben has resulted in the preservation of younger Cretaceous and Tertiary rocks in the structural low.

## Major Faults

The pre-basalt paleogeologic map (fig. 13) shows a northwest-trending down-to-the-west fault in the center hereafter referred to as the Black Gap fault. More than 500 feet of Pen Clay to the west of the fault and its absence east of the fault is evidence that the faulting antedated extrusion of the basalt. It is probably the oldest fault in the area. A mile west of the Big Horn sheep pasture the fault surface is exposed in a water gap. Dip of the fault is 62° W. This is the only normal fault in the area definitely not near-vertical.

A mile south of Black Gap a near-vertical normal fault down to the east terminates at the older Black Gap fault. The fault extends southeast to the Rio Grande and forms the northeast edge of the fault block southwest of Horse Canyon. The fault has approximately 600 feet of throw.

The total displacement of normal faults separating the Black Gap graben and the Cupola Dome is down to the southwest a maximum of 1,200 feet. At the head of Whiskey Canyon (pl. 1, K-5) a fault exposes Glen Rose Limestone to the northeast in contact with Santa Elena Limestone to the southwest.

There are several northeast-trending faults in the map area, but only two are large enough to be significant. Whiskey Canyon, northeast of Maravillas Canyon, and Dog Canyon (pl. 1, J-7) to the southwest are located along the trace of a northeast-trending fault down to the northwest with less than 200 feet of throw. The fault is significant because of its length.

The northeast-trending fault which marks the eastern flank of the Dove Mountain Ranch anticline extends more than 12 miles and terminates the tight fold of Stillwell anticline. This suggests that the faulting is older than folding in the area. The fault also terminates the Serrania del Burro arch. Throw is variable along this fault and actually reverses near the intersection with Stillwell anticline. The throw is at a maximum of 1,400 feet near the north boundary of the map area.

## Stillwell Anticline

Stillwell anticline is probably the most impressive single structural feature in the Black Gap area. It is asymmetrical with its axial plane inclined to the northeast. Although less than a quarter of a mile wide it is nearly eight miles long. Structural relief along the anticline is approximately 300 feet.

Figure 27. Southeastward aerial view of Stillwell anticline; asymmetrical folding inclined to northeast; Stillwell Mountain in right background.

All strata younger than Santa Elena Limestone have been stripped from the anticline leaving the competent, resistant limestone core. This feature is a décollement which slid along the underlying incompetent Sue Peaks Formation over the massive Del Carmen Limestone. Inclination of the axial plane to the northeast suggests overthrust movement from the southwest. There are similarly shaped folds in the lower Ernst Member flaggy limestone beds (fig. 28).

Figure 28. Southeastward view of asymmetric folding in lower flaggy limestone beds of the Ernst Member two miles west of the southern tip of Stillwell anticline; axial plane of fold trends N. 40° W. and dips southwest as does the axial plane of Stillwell anticline.

The asymmetrical folding was caused by uplift of the Sierra del Carmen area followed by décollement sliding of massive limestone over incompetent shale and silty claystone to the northeast across the Black Gap area. Vertical movement of basement blocks possibly initiated uplift of the Sierra del Carmen. Gravity moved the rocks downdip away from the Sierra del Carmen high and toward the northeast. Shortening of the crust by folding resulted in folds with axes normal to direction of movement, such as the Stillwell anticline with an axis trending N. 40° W.

### Black Gap Syncline

Parallel with and two miles to the west of Stillwell anticline is the Black Gap syncline. This feature is a relatively tight fold in the area of the Black Gap headquarters but opens out into the broad alluvial-filled valley to the northwest (pls. 1 and 2). The pre-basalt paleogeologic map (fig. 13) indicates that negative movement in this area had begun prior to volcanism.

Continued downwarp and faulting occurred after the basalt cover was extruded. The basalt layers now dip approximately 35° toward the synclinal axis along both sides of the syncline (fig. 16).

### Dove Mountain Ranch Anticline

In the north-central part of the map area is the broad, asymmetrical, north-northeast-trending Dove Mountain

Ranch anticline. The anticline has been breached along its crest by erosion and the Del Carmen Limestone is exposed in the center. The Santa Elena Limestone is exposed along the flanks and on the southward-plunging nose.

The anticlinal axis of the fold is less than half a mile west of the termination of the southeast flank against the northeast-trending fault. East of the anticlinal axis the average dip is 25° SE. Immediately west of the axis the average dip is 10-15° W., but three miles west the average dip is 5° W. The westward-dipping west flank of the anticline also forms the northeast flank of the alluvial-filled part of the Black Gap syncline (pls. 1 and 2). The fold plunges southward immediately north of Maravillas Creek (pl. 1, G-3). The anticline follows an arcuate course through the Dove Mountain quadrangle (fig. 2) and opens out to the north into the Marathon Dome.

A major fault striking approximately N. 30° E. marks the eastern edge of the anticline (fig. 29). The interior part of the fold is faulted (pls. 1 and 2) and throw is reversed along some of these faults. The anticline and associated faults have the same trend as do the Paleozoic structures to the north in the Marathon Basin. This suggests that the anticline is a result of rejuvenation along Paleozoic fault trends and probably marks the border between the frontal and interior zones of the Ouachita System.

Figure 29. Aerial view to north-northeast along faulted east flank of Dove Mountain Ranch anticline. Outcrop of steeply dipping Del Carmen Limestone in center separated by fault from Santa Elena Limestone on right.

## Slip-slabs

Two slabs of green-alga biosparite (unit 35, pl. 3) in lowermost Buda Limestone lie on the lower massive Buda Limestone (unit 36, pl. 3) west of the anticlinal fold a mile northwest of Dell Tank (pl. 1, H-6).

Figure 30. Northwestward view of slip-slab of lowermost Buda Limestone resting on younger Buda Limestone.

These slabs slid westward off the crest of the adjoining tightly folded anticline.

Harrison and Falcon (1934, 1935) discussed similar features from southwestern Iran. In Iran, as in the Black Gap area, sliding of slabs of sedimentary rock accompanied by relatively little fracturing occurred where massive limestone was underlain by shale or marl.

Harrison and Falcon pointed out that many thousands of feet of overburden plus great relief aided in the extensive displacements they observed. Probably neither existed in the Black Gap area. Thickness of overburden was probably never more than 3,000 feet. Relief of the units involved is on the order of 50 feet. Displacements observed are on the order of 300 feet. The following sketch illustrates the probable evolution of the slip-slab:

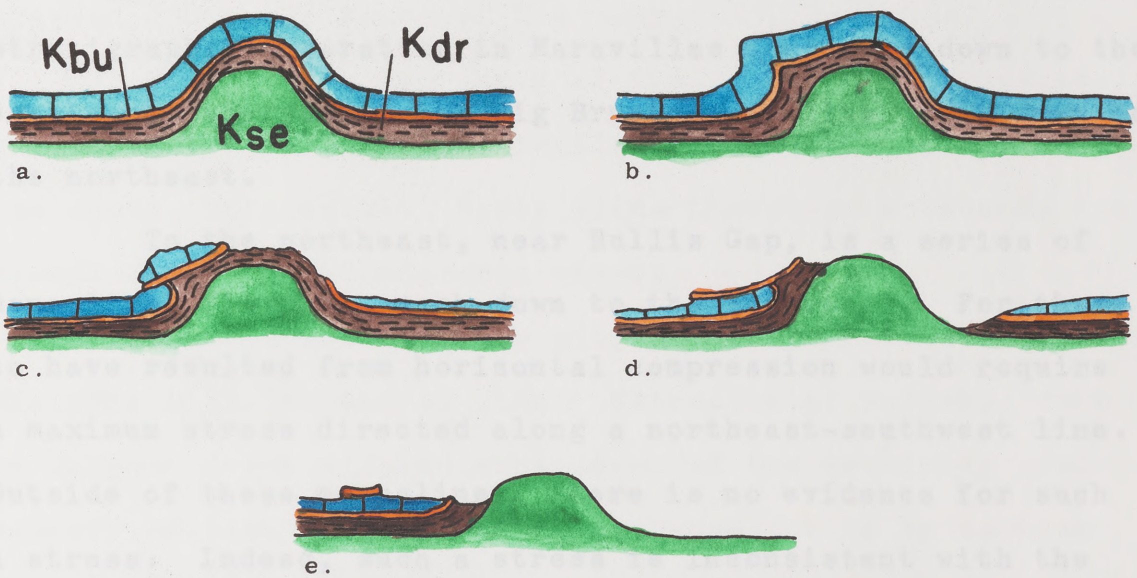



Figure 31. Evolution of the slip-slabs near Dell Tank; a) anticline before erosion, b) formation of an incipient knee-fold by gravitational creep or structural overfolding, c) breaking and overriding of the Buda Limestone, d) progressive gravity movement of the slab, e) erosion resulting in the present outcrop pattern.

## Maravillas Canyon Monocline

A monocline extending northwest from the mouth of Maravillas Canyon has lowered the section on the southwest side of the canyon approximately 200 feet relative to the northeast side. Maravillas Canyon occupies the zone of flexure and the monocline is not obvious. Nevertheless, there is a distinct roll-over of beds in Maravillas Canyon five miles from the Rio Grande.

The Maravillas Canyon monocline has a sense of motion opposite to that of the Big Brushy monocline. Relative stratigraphic separation in Maravillas Canyon is down to the southwest, whereas in the Big Brushy monocline it is down to the northeast.

To the northeast, near Bullis Gap, is a series of monoclinal flexures, each down to the southwest. For these to have resulted from horizontal compression would require a maximum stress directed along a northeast-southwest line. Outside of these monoclines, there is no evidence for such a stress. Indeed, such a stress is inconsistent with the regional structural pattern. More likely, the monoclines of the area formed as a result of draping over basement blocks. If so, a series of faults down to the southwest must extend from the north beyond Bullis Gap southward to the fault marking the northeast boundary of the Black Gap graben. Stratigraphic separation dies out to the west and northwest along each of the monoclines.

## Pinto Tank Collapse Feature

Pinto Tank, an earthen tank in the south part of the Dove Mountain Ranch, is in a pocket of Del Rio Formation and Buda Limestone (fig. 15). Extrusive basalt caps a low hill 200 yards west of the tank, and an intrusive basalt plug is exposed 100 yards south of the tank.

East, west, and north of the pocket are bordering faults that have allowed a section, hinged by a flexure to the south, to subside. Santa Elena Limestone surrounds the pocket of younger Cretaceous strata.

The intrusion of the plug probably initiated events. The plug fills a vent or pipe. Extrusion of material from an unknown depth allowed subsidence of the overlying sedimentary section along zones of weakness set up by earlier compression. Erosion followed subsidence, removing the extruded igneous rock and planing the sedimentary strata. The extrusive basalt capping the low hill west of the tank represents the latest event and differs from the intrusive basalt in being finer grained and containing no biotite. The basalt flowed up the fault zones bordering the collapsed area. The Santa Elena Limestone is metamorphosed away from the fault trace for approximately 15 feet. Recent erosion has produced the present outcrop.

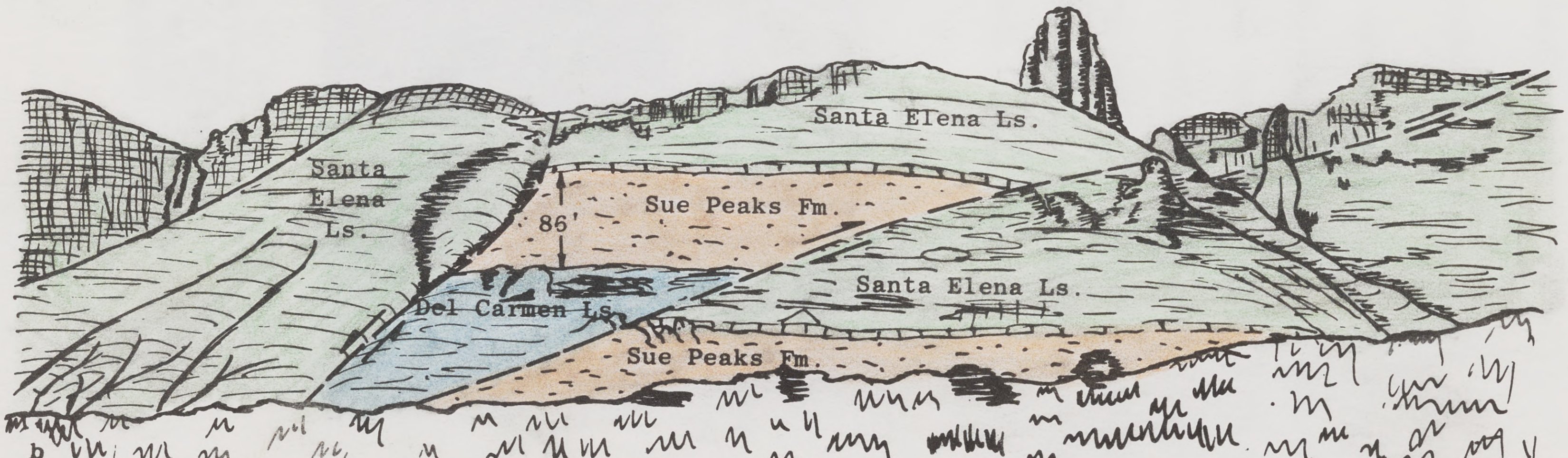
## Maravillas Canyon Thrust Fault

Five miles northwest from the Rio Grande and one mile northeast of Maravillas Canyon is a spoon-shaped thrust fault terminated at its lower end by a normal fault (fig. 32). Exact displacement is unknown but approximately 100 feet of reverse throw can be demonstrated. The upper part of the Del Carmen Limestone in the hanging wall is in contact with the lower part of the Santa Elena Limestone in the foot wall.

The east trace of the thrust fault is well exposed where the fault surface dips 25° to the west. The fault can be traced along a narrow ridge to the north and along the top of the mountain to the west. At its northernmost limit dip of the fault surface is approximately 20° to the south. The fault can be traced to the west where it enters a topographic trough extending to the southwest; the trough is littered with debris and caliche. Numerous joints in the trough area dip 20-25° to the southeast. The southern extremity of the trough is the same down-to-the-south normal fault that terminates the eastern fault trace.

Thus the fault trace surrounds an area approximately half a mile in diameter, and it dips toward the center. This feature is additional evidence for northeastern movement away

a




b

Figure 32. Northwestward view of thrust fault north of Maravillas Canyon (pl. 1, K-7): a) photomosaic, and b) sketch section illustrating formation contacts, fault traces, and approximate scale.

from the uplifted Sierra del Carmen.

## STRUCTURE OF CUPOLA DOME

In the northeast corner of the map area is a broad, domed area representing the northwest extension of the Serrania del Burro. An arcuate fault zone with maximum throw of 1,200 feet (pls. 1 and 2), extending northwest from the Rio Grande to Cupola Mountain and north to the west of Dove Mountain, separates the uplifted block from the Black Gap graben to the southwest (fig. 33).

Figure 33. Aerial view to north of Cupola Mountain (pl. 1, K-3) showing downthrown jointed and faulted Santa Elena Limestone surface in foreground. Major fault at foot of scarp which forms skyline.

Cupola Dome (pl. 2) is elongated along a northwest trend and has approximately 200 feet of closure. Erosional remnants of younger Cretaceous rocks capped with Tertiary extrusive basalt remain at Cupola Mountain peak, Black Mountain, and Dove Mountain thus dating the marginal faulting as post-basalt. The dome itself is unfaulted except for very minor north-northwest-trending faults on the east flank.

Big Canyon and Rio Grande Canyon are to the east of Cupola Dome. A narrow ridge cut by minor northwest-trending faults (fig. 34) separates Big Canyon and the Rio Grande Canyon.

Figure 34. Aerial view to south along ridge between Big Canyon and Rio Grande Canyon (pl. 1, O-2). The Del Carmen Limestone caps the scarp in upper left. The light colored band is the Sue Peaks Formation beneath the Santa Elena Limestone. Small graben in lower center.

## ANALYSIS OF STRUCTURAL FEATURES

The fracture and fold pattern of the Black Gap area indicates several structural events, distinct yet related.

Dove Mountain Ranch anticline lies athwart the trend of all other structures in the area. If it is extended southwest along trend to the Sierra del Carmen, it is found to divide the reverse faulted portion to the north from the asymmetric folding to the south. This difference is inferred to reflect a change in rock types underlying the Cretaceous from Paleozoic sedimentary rocks such as are exposed in the Marathon Basin immediately to the north to metamorphic rocks such as are exposed near Boquillas, Mexico immediately southwest of the area. The Dove Mountain Ranch anticline thus lies above the inferred boundary between the frontal and interior zones of the Ouachita System as used by Flawn and others (1961, p. 169).

Stillwell anticline, Big Brushy monocline, and the Maravillas Canyon thrust fault are believed to have resulted from décollement to the northeast from an uplifted Sierra del Carmen. The Sierra del Carmen strikes approximately N. 20° W.; therefore movement away from the uplift would be in a N. 70° E. direction. This is approximately the direction of movement of the thrust fault and both Big Brushy monocline and Stillwell anticline strike normal to the proposed direction of movement. Big Brushy monocline is down to the east and Stillwell anticline is asymmetrical to the east. These are additional evidence for movement to the northeast. Each of these features is cut by younger near-vertical normal faults.

A rhombic pattern of joints and faults in two principal sets are found in the Sierra del Carmen area. The dominant set strikes approximately N. 20° W., and the minor set approximately N. 75° W. Throw suggests that movement was contemporaneous along both sets. The sets have essentially vertical dips and an intersection angle of approximately 55°. This suggests an origin as conjugate strike-slip faults having maximum principal stress trending approximately N. 47° W. and minimum principal stress striking approximately N. 43° E. (fig. 35).

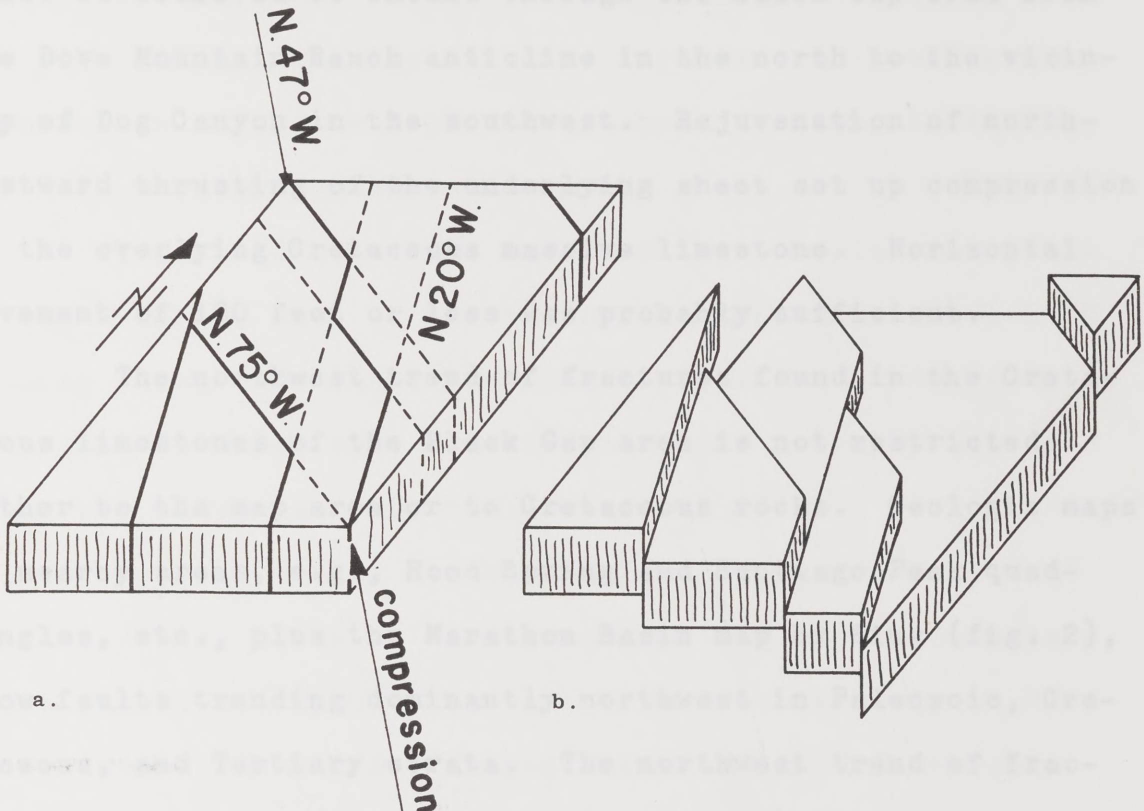



Figure 35. Diagrammatic interpretation of structural development of Sierra del Carmen area; a) conjugate strike-slip shears resulting from northwest-southeast maximum horizontal principal stress and northeast-southwest minimum principal stress (not shown), b) fault pattern developed along shear sets following reduction of horizontal compression and inception of vertical downdrop. (Modified after Donath, 1962, p. 13, fig. 9.)

The stress pattern requires maximum horizontal compression acting along a N. 47° W. trend. This is the direction of motion of the late Paleozoic thrusts of the Marathon

Basin (King, 1937, pl. 15). The frontal edge of the thrust sheet is believed to extend through the Black Gap area from the Dove Mountain Ranch anticline in the north to the vicinity of Dog Canyon in the southwest. Rejuvenation of northwestward thrusting of the underlying sheet set up compression in the overlying Cretaceous massive limestone. Horizontal movement of 100 feet or less was probably sufficient.

The northwest trend of fractures found in the Cretaceous limestones of the Black Gap area is not restricted either to the map area or to Cretaceous rocks. Geologic maps of nearby areas, e.g., Hood Spring and Santiago Peak quadrangles, etc., plus the Marathon Basin map by King (fig. 2), show faults trending dominantly northwest in Paleozoic, Cretaceous, and Tertiary strata. The northwest trend of fractures observed throughout the region is probably related to the same source. Late Paleozoic northwest overthrusting can be demonstrated. It is possible that the Paleozoic orogeny was caused by sub-crustal movement. A recurrence of sub-crustal activity following Tertiary volcanism explains the northwest-trending fracture pattern in the Cretaceous and younger rocks. The sub-crustal movement caused compression of the overlying crystalline and sedimentary rocks, setting up conjugate shear sets. It is possible that the shear sets developed in the crystalline and overlying sedimentary rock and even the extrusive Tertiary basalt. Strike-slip movement along the shear sets or, more probably, cessation of the sub-crustal activity effected a release of horizontal compression which was followed by block faulting involving vertical movement of basement blocks.

King (1937, p. 140) inferred that the latest uplift of the Marathon Dome to the north accompanied by subsidiary folding along the flanks occurred in Late Eocene or Early Oligocene at which time dip-slip movement probably occurred along the older near-vertical shear sets.

Everett (1964) has shown that the thrust faults of Del Norte Gap, north of Persimmon Gap (fig. 3), become vertical faults at depth. The same situation probably is true at Persimmon Gap and Dog Canyon, thus explaining the so-called thrust faults.

A mile east of Black Gap along the south bank of the main drainage course is a near-vertical fault down to the west approximately 20 feet. The fault strikes N. 24° W. On the east side of the fault are drag folds in the Ernst Member of the Boquillas Formation. The folds in the flaggy limestone beds strike N. 06° E. The folds are in beds two inches thick and have an amplitude of six inches and a period of 24 inches. The folds make an angle of 30° with the fault indicating left-lateral strike-slip movement. Such movement would give the effect of a couple as illustrated below:

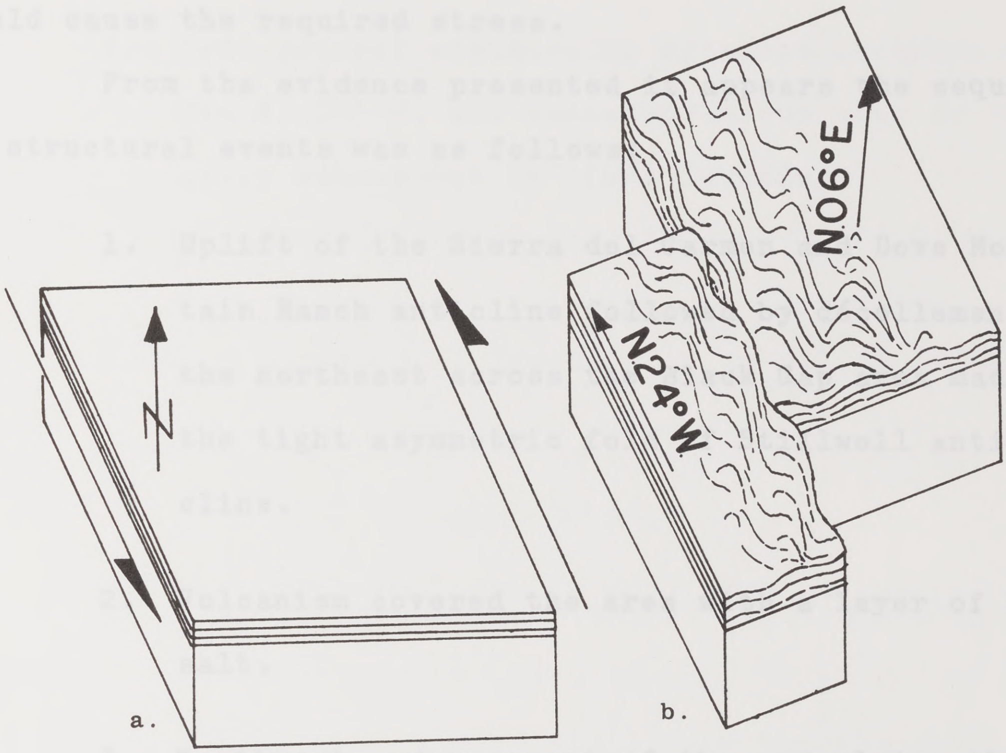



Figure 36. Folds associated with a left-lateral couple; a) undeformed block prior to application of couple, b) deformed block after coupling action showing left-lateral strike-slip movement and associated folding.

If the compression resulted from northwestward movement of the underlying Paleozoic thrust sheet and movement was greater to the north of the map area than to the south, the effect would be that of a couple. Although the left-lateral strike-slip movement suggests a couple, one is not essential in this situation. Preferential movement along the N. 20° W. shear of the conjugate shear-set (fig. 35) would cause the required stress.

From the evidence presented it appears the sequence of structural events was as follows:

1. Uplift of the Sierra del Carmen and Dove Mountain Ranch anticline followed by décollement to the northeast across the Black Gap area made the tight asymmetric fold of Stillwell anticline.

2. Volcanism covered the area with a layer of basalt.

3. Northwestward movement of the underlying thrust sheet was accompanied by slight rejuvenation of Paleozoic structural features.

4. Northwestward movement of the underlying thrust sheet resulted in horizontal compression in the massive Cretaceous limestones. Conjugate shear sets striking N. 20° W. and N. 75° W. formed but little or no movement occurred.

5. Reduction of horizontal compression permitted

block faulting along the previously formed shear sets.

6. Left-lateral strike-slip movement occurred along the N. 20° W. set contemporaneous with or immediately subsequent to block faulting.

# G E O L O G I C   H I S T O R Y

The lack of surface exposures of pre-Cretaceous rocks within the map area precludes interpretation on a local basis for that era. Consideration of regional geology, based on the work of others, does however furnish information for the interpretation of pre-Cretaceous geologic history.

Nothing is known of Precambrian events in Brewster County.

## PALEOZOIC ERA

King (1937) described in detail the stratigraphy, structure, and evolution of the Paleozoic rocks of the Marathon Basin. Flawn and others (1961) have incorporated King's classic work into their regional study of the Ouachita System. Ellison and others (1964) have added to the knowledge of the facies relationships of the Paleozoic strata. The following briefly summarizes previous work.

Cambrian, Ordovician, and Devonian rocks of the Marathon region are transitional from a predominantly clastic facies to the south and southeast and a carbonate foreland shelf facies to the north and northwest. The Tesnus Formation of Mississippian and Pennsylvanian age is a southward-thickening wedge of flysch deposits, which marks the beginning of a major tectonic event. The axis of the geosyncline which had previously been located to the southeast shifted northwestward and previously formed rocks to the southeast became source rocks for clastic sediments. Overthrusting from the south and southeast during the Pennsylvanian formed northeast-trending structures, which in part determine the present outcrop pattern. Another northward shift of the geosynclinal axis occurred near the end of the Pennsylvanian. Permian carbonate rocks overlying Pennsylvanian strata form the Glass Mountains, whereas older Permian clastic rocks are present to the north in the Val Verde Basin.

Flawn and others (1961, p. 168), on the basis of petrographic studies, mapped two main structural units within the Ouachita System, a frontal zone containing unmetamorphosed to weakly metamorphosed sedimentary rocks and an interior zone containing sedimentary rocks showing weak to low-grade metamorphism and having shear features.

Overthrusting carried rocks of the interior zone northwest over rocks of the frontal zone along a northeast-trending front extending through the Black Gap area.

## MESOZOIC ERA

Post-Permian uplift and erosion deformed and planed the Paleozoic strata. The Mesozoic sea filled the negative Mexican Geosyncline and Sabinas Basin to the south (fig. 19) and continued its northward advance until the Coahuila and Tamaulipas Platforms were inundated. The Comanchean sea deposited the Glen Rose Limestone upon the eroded surface. The massive Del Carmen and Santa Elena Limestones thin toward the Glass Mountains, indicating incipient uplift of the Marathon area. Minor folding occurred before or during deposition of the Del Rio Formation.

Comanchean deposits are predominantly shallow-water limestones whereas the occurrence of silt and clay in the Gulfian rocks suggests retreat of the shoreline and emergence of the Marathon Dome.

## LATE CRETACEOUS-TERTIARY PERIODS

Late Cretaceous or Early Tertiary uplift of the Sierra del Carmen and Dove Mountain Ranch anticline and associated décollement to the northeast formed the asymmetric Stillwell anticline. This activity was probably related to the Laramide Orogeny.

Igneous intrusive and extrusive rocks are possibly of Late Eocene or Early Oligocene age.

Rejuvenation of northwestward thrusting of the underlying Paleozoic thrust sheet caused compression and set up conjugate shear sets in the massive Cretaceous limestones and possibly in the Tertiary extrusive basalt. The northwestward thrusting of the Paleozoic thrust sheet may have been related to sub-crustal activity which would also have affected the underlying crystalline rocks.

Release of compression allowed block faulting along the conjugate shear sets. The block faulting involved vertical movement of basement blocks. The block faulting is probably younger than Oligocene and possibly related to Basin and Range events.

## QUATERNARY PERIOD

### Drainage Development

The Rio Grande, which forms the southeast boundary of the map, is the drainage base for the region. When the Rio Grande originated as a flowing stream in its present course is still a major unresolved geologic problem. The following observations and conclusions are offered as suggestions.

Blackwelder (1934, p. 560-562) postulated a series of integrated inland basins for the origin of the Colorado River. He believed that the Colorado River originated as late as the Pleistocene, and Longwell (1946, p. 826) offered evidence to prove the Colorado River, as a through-flowing stream, can be no older than the Miocene.

The Horse Heaven Hills in Washington were uplifted faster than the Columbia River could erode (Warren, 1941, p. 227). The river aggraded and water spilled over the crest at a low point, thus becoming a cross-axial consequent stream. The following line of reasoning suggests that the Rio Grande crossed the Sierra del Carmen in a similar manner.

It is generally accepted that the southwestern United States had an arid to semi-arid climate in the latter part of the Tertiary Period (King, 1959, p. 128) during which numerous playas and inland basins existed. Pleistocene glaciation altered the climate and a pluvial cycle followed (Flint, 1957).

In a region containing numerous inland basins, overfilling and gradual integration of such features would normally occur during a pluvial cycle such as began during the Pleistocene. During such an event, some bolson deposits would not be integrated into the main system and would remain isolated. Examples of such isolated bolson deposits flanking the Rio Grande are Salt Basin near Van Horn, Texas, and

Cuervo Bolson, Chihuahua.

It is probable that a series of unconnected basins separated by ridges or low mountains occupied much of the area now integrated into the Rio Grande drainage system in Trans-Pecos Texas. The Hueco Bolson in Hudspeth County, Texas, is an example of a bolson fill entrenched during the Pleistocene by the Rio Grande. Strain (1959, p. 377) found vertebrate remains in the Hueco Bolson that demonstrated that the Rio Grande began to entrench the bolson fill between late Kansan (second Pleistocene glaciation) and middle Illinoian (third Pleistocene glaciation).

A lake formed on the upstream side of the Sierra del Carmen. Eventually the water rose high enough so that it spilled over the crest of the Sierra del Carmen at a topographically low point. Gravel terraces south and east of the Chisos Mountains (fig. 3) probably indicate later periods of downcutting into the fill.

The Rio Grande crosses the Sierra del Carmen at a cross-axial topographic low that resulted from a structural reversal. Fault blocks of the Sierra del Carmen are down to the northeast on the Texas side of the river whereas on the Mexico side the fault blocks are down to the southwest. Why the structural reversal exists has not been determined.

There remains the problem of why the drainage flows east and not west and north of Cupola Mountain (pl. 1). The basalt flows, as indicated by thicknesses at Stillwell Mountain and Black Gap syncline, were extensive and probably covered an area from north of Dove Mountain (fig. 3) south to a point near Persimmon Gap and southeastward along the front of the Sierra del Carmen. The basalt probably filled in the topographic low west of Cupola Mountain thereby blocking stream migration and channeling the Rio Grande into the topographic low to the east.

The Rio Grande is thus probably a consequent stream north of the Big Bend and a cross-axial consequent stream in the Black Gap area.

Maravillas Creek, which heads near Alpine, is the major tributary stream in Brewster County to the Rio Grande. It parallels the trend of the Santiago Mountains in its upper reaches and maintains its course in the topographically lower, more easily eroded strata to the east of the mountains. It follows the trend of a post-Cretaceous syncline from Del Norte Gap (fig. 3) to a point near the Stillwell Ranch headquarters where it enters a fault line scarp of massive Comanchean limestone. The incompetent Gulfian strata crop out south and west of this point at a lower topographic level and the question arises as to why the stream did not follow this more easily eroded path. As previously stated, the basalt probably extended over this area south to the Sierra del Carmen. The uppermost basalt on Stillwell Mountain is approximately 3,600 feet above sea level, more than 300 feet lower than the basalt on Cupola Mountain. This is additional evidence for post-volcanism faulting which lowered the Black Gap graben and formed a northwest-trending trough in the basalt. Headward erosion from the Rio Grande along this trough probably initiated Maravillas Creek which eventually cut through the basalt and incised the underlying Comanchean limestone southeast of the Stillwell Ranch headquarters. This evidence indicates that Maravillas Creek is superposed on the Comanchean strata southeast of the Stillwell Ranch headquarters whereas northwest of the headquarters it is subsequent, having eroded headward on the Gulfian strata.

Several wind and water gaps occur in the Santiago Mountains and the Sierra del Carmen, e.g., Del Norte Gap, Persimmon Gap, and Dog Canyon. King (1937, p. 13) believed the gaps resulted from westward drainage off the Marathon Dome. He also believed erosion by subsequent streams in the weak rock of the Marathon Basin captured and reversed the flow from west to east. If so, the capture must have been effected by a headward eroding Maravillas Creek.

The fault block between Stillwell and Heath Canyons (pl. 1) dammed the Rio Grande at a time more recent than the entrenchment of the Sierra del Carmen. The age of the fill is unknown but it post-dates the major faulting as the fill overlaps some of the tilted fault blocks (pl. 1). The river formed a lake southwest of the fault block and aggraded to the level of the block at which time the water spilled over and began to incise the block. Successive terrace levels in the bolson fill attest to halts in downcutting. The uppermost level of bolson fill in the Black Gap area is approximately 2,500 feet above sea level, well below the upper surface of the Sierra del Carmen.

# E C O N O M I C   G E O L O G Y

## WATER

The paucity of water accounts for the scarcity of settlers in this country. Most of the rainfall falls rapidly as thundershowers and runs off into the intermittent streams which empty into the Rio Grande. Rainfall is infrequent and torrential when it occurs. Flashfloods are common during the rainy season.

There are no natural bodies of standing water in the area although several man-made earthen tanks hold water and serve as a gathering place for wildlife.

Water wells in the area furnish good water at depths from 300 to 1,000 feet. The reservoirs are without exception fractured, massive limestones.

Several valleys are filled with Quaternary alluvial material but attempts to develop water in them have not been successful. Numerous dry wells have proven that the gravel- and silt-filled valleys lack aquifers. Either the clay fraction in such deposits has resulted in low permeability or else fractures in the underlying limestone have drained reservoirs.

Numerous sinkholes in the Buda Limestone and caves in the other massive limestones attest to solution.

## SOIL

Attempts have been made to irrigate the alluvial soil along Maravillas Creek between the Stillwell Ranch and State Highway 385 as well as similar soil in Stillwell Canyon and along the Rio Grande near the Adams Ranch. Lack of an adequate water supply plus the presence of salt in the soil has made these efforts only partly successful.

## BARITE

A barite deposit west of Big Brushy Canyon has been mined. A road (fig. 23) leads from Big Brushy Canyon to the mine. The barite occurs as a joint filling in the fractured Santa Elena Limestone. No information on amount of ore mined is available.

## SEMI-PRECIOUS STONES

The deposits of Quaternary older gravel contain chert, chalcedony, and an abundance of the so-called "moss-agate." Local rock shops sell the stone and it is used for inexpensive jewelry.

## FLUORITE

Numerous fluorite deposits occur in nearby areas.

East of the Black Gap area in Mexico is the La Linda fluorite deposit operated by Dow Chemical Company. Also, a deposit of commercial quality and quantity reportedly occurs to the west in the Big Bend National Park.

Daugherty (1962) determined that the fluorite of the La Linda deposit is a contact-metasomatic deposit associated with intrusion of rhyolite into the massive Cretaceous Santa Elena Limestone.

The presence of intrusive plugs and sills in the Black Gap area plus the presence of the massive Del Carmen and Santa Elena Limestones makes the occurrence of fluorite possible, yet none has been found.

It is possible that Cupola Dome was caused by intrusion. If a petrologically favorable intrusion occurred mineralization might occur in the limestone of the Del Carmen and Santa Elena. Depth of a possible host might also affect the mineralization.

## SILVER

A prospect pit in a calcite vein within the Glen Rose Limestone reportedly was a silver prospect. The pit is located on the geologic map (pl. 1, M, N-6).

A spectrographic analysis (Schofield, 1965) of samples from the prospect indicated an amount of silver less than 0.0001 percent.

## PETROLEUM

Traces of dead oil stain (?) occur in the Glen Rose Limestone and freshly broken surfaces of Glen Rose Limestone and limestone beds in the Sue Peaks Formation have a petroliferous odor. An oil scum reportedly developed on cuttings from a well drilled near Dove Mountain. An odor of sulfide was also present.

Source rocks, reservoir rocks, and structural traps are present in the area, yet little or no petroleum exploration has been attempted. The prospective Cretaceous section is exposed at the surface, thereby eliminating it from consideration. The underlying Paleozoic section is considered to be of unfavorable facies in addition to being complexly faulted.

I would classify the region as one of very low priority for exploration.

APPENDIX

## MEASURED SECTIONS

The location of each of the five measured sections composing the composite measured section (pl. 3) is marked on the geologic map (pl. 1).

MS-1.--lat 29°34'15" N., long 102°58'30" W.
The section begins at the south base of the tallest of the group of low hills and ends at the edge of the gravel-covered terrace to the east.

MS-2.--lat 29°35'53" N., long 102°55'25" W.
At the east end of the east-west-trending valley the southern scarp swings sharply to the south. The section begins approximately 200 yards from the corner at the base of the east-facing scarp. The section ends at the base of the overlying massive lower Buda Limestone.

MS-3.--lat 29°35'47" N., long 102°46'00" W.
An abandoned goat camp with fences, corrals, and a small shack is situated along the road beside the Rio Grande. The base of the section is located 300 yards east of the shack at the bank of the Rio Grande and the section extends west along the fence line to the base of the cliff-forming Del Carmen Limestone. The base of the offset part of the section begins at a wire drift fence which closes one of the canyons leading to the top of the ridge. The top of the section is at the base of the overlying Santa Elena Limestone.

MS-4.--lat 29°30'00" N., long 102°48'56" W.
A sharp bend in Drift Canyon marked by fault breccia and the first occurrence of yellowish orange silty clay denotes the base of the section. The top of the lower part of the section is at the base of a cherty bioherm approximately 30 feet thick. The top of the offset part of the section is at the base of the flaggy limestone beds of the Ernst Member.

MS-5.--lat 29°30'40" N., long 102°54'33" W.
The base of the section begins at the bottom of the depression in the yellowish gray clay of the San Vicente Member. The section continues upward to the top of the overlying basalt.

# PETROGRAPHIC DESCRIPTIONS

A 300-point count was made on each of the following thin-sections to determine the constituent percentage. The descriptive format is as follows:

Rock name; stratigraphic unit; thin-section number; location. Description.

| Constituent | % |
|---|---|

Green alga biosparite.--Buda Limestone; BTx-M1-2c; cross-bedded ledge former at base of Buda at MS-1, unit 35 on composite section (pl. 3). Algae and fossil fragments have thin micrite coating, sparry calcite averages 0.05 mm diameter and formed later than micrite; green algae average 0.30 mm diameter and pellets about 0.01 mm.

| Constituent | % |
|---|---|
| sparry calcite | 52 |
| green algae | 32 |
| pelecypod fragments | 7 |
| fossil fragments | 7 |
| micrite | 1 |
| pellets | 1 |

Analcime gabbro.--Tertiary sill; BTx-M1-6; intruded in Ernst Member at MS-1, unit 41 on composite section (pl. 3). Fine to medium holocrystalline, non-porphyritic; zoned plagioclase laths to 3 mm long partly altered to zeolite; analcime generally anisotropic and late- or post-magmatic filling voids and cracks in feldspar; aegirine-augite crystals zoned.

| Constituent | % |
|---|---|
| plagioclase | 76 |
| analcime | 12 |
| aegirine-augite | 6 |
| iron oxide | 5 |
| calcite | 1 |
| apatite | tr |
| biotite | tr |
| leucoxene | tr |

Poorly washed green alga biosparite.--Buda Limestone; BT-M2-3; cross-bedded ledge former at MS-2, unit 35 on composite section (pl. 3). Contains green algae and fragments of pelecypods, gastropods, and brachiopods; micrite about 0.004 mm diameter and coats fossil fragments; sparry calcite formed later and filled void spaces and cracks, average grain

| Constituent | % |
|---|---|
| micrite | 32 |
| sparry calcite | 24 |
| green algae | 26 |
| pelecypod fragments | 8 |
| fossil fragments | 9 |
| pellets | 1 |

diameter 0.03 mm; green algae about 0.7 mm diameter.

Basalt.--Tertiary sill; BTx-S-8; intruded into Glen Rose Limestone, taken from mine shaft by road beside Rio Grande near northeast boundary of Black Gap Wildlife Management Area (pl. 1, P-3). Fine-grained holocrystalline, nonporphyritic; plagioclase partly altered to sericite; biotite partly altered to fine-grained chlorite; amphibole brown to purple, probably contains titanium.

| | |
|---|---|
| plagioclase | 49 |
| biotite | 13 |
| titanaugite | 12 |
| amphibole | 9 |
| iddingsite | 6 |
| augite | 5 |
| magnetite | 4 |
| analcime | 2 |
| apatite | tr |
| calcite | tr |
| leucoxene | tr |

Intrusive basalt breccia.--Tertiary dike; BTx-S-10a; intruded along fault on east flank of Dove Mountain Ranch anticline (pl. 1, H-1). Merocrystalline, microcrystalline to medium-grained porphyritic; micro-xenoliths or volcanic rock fragments to 6.5 mm long are basalt and exhibit vesicles and plagioclase laths which indicate flow structure; dark microcrystalline matrix plagioclase rich; augite phenocrysts average 0.5 mm diameter and plagioclase fragments average 0.2 mm.

| | |
|---|---|
| matrix | 57 |
| volcanic rock fragments | 40 |
| augite | 3 |
| plagioclase | tr |

Olivine basalt.--Tertiary dike; BTx-S-10b; same location as BTx-S-10a. Fine to medium holocrystalline, porphyritic; euhedral olivine has altered completely to iddingsite pseudomorphs; augite greatly altered; flow structure; calcite fills vesicles.

| | |
|---|---|
| plagioclase | 62 |
| iddingsite | 17 |
| augite | 15 |
| calcite | 4 |
| magnetite | 2 |

Basalt.--Tertiary plug; BTx-S-14; east of Dove Mountain Ranch anticline (pl. 1, H-2). Fine grained holocrystalline, porphyritic, trachytic; plagioclase fragments rounded and partially resorbed;

| | |
|---|---|
| plagioclase | 74 |
| hematite/ magnetite | 17 |
| augite | 5 |
| calcite | 2 |
| leucoxene | 2 |

| | | |
|---|---|---|
| plagioclase probably andesine ($An_{45}$); augite phenocrysts partly resorbed, some augite has leucoxene coronas surrounded by rim of hematite. | | |
| Basalt.--Tertiary plug; BTx-S-17; about 300 yards west of Cupola Mountain peak at contact of Santa Elena Limestone and Del Rio Formation (pl. 1, K-3). Holocrystalline, non-porphyritic; fine- to medium-grained, crystals to 1.5 mm diameter; olivine completely altered to iddingsite; pyroxene not same as in sills, may contain both clinopyroxene and hypersthene; plagioclase is andesine ($An_{44}$). | plagioclase<br>pyroxene<br>iddingsite<br>magnetite | 62<br>28<br>8<br>2 |

The following thin-sections are taken from samples from the Pinto Tank area on the Dove Mountain Ranch. For sample location index, see figure 15.

| | | |
|---|---|---|
| Olivine basalt.--Tertiary extrusive; C-B; extrusive mass beside Pinto Tank on Dove Mountain Ranch. Holocrystalline, non-porphyritic, trachytoid; olivine partly altered to iddingsite; plagioclase altered to sericite. | plagioclase<br>iddingsite<br>olivine<br>magnetite | 67<br>24<br>7<br>2 |
| Sanidine quartz welded tuff.--Quaternary lag gravel; C-8; cobbles strewn around Pinto Tank area. Crystal fragments to 1.8 mm diameter composed of sanidine, quartz, and plagioclase. | glassy matrix<br>glass shards<br>crystal fragments<br>calcite | 64<br>22<br>14<br>tr |
| Marble.--Tertiary metamorphosed Santa Elena Limestone; C-10a; Pinto Tank area. Rock was pelecypod biosparite before weak metamorphism; spar and micrite percentage here reflects present grain size and may not reflect depositional fabric; sparry calcite grains average 0.04 mm diameter; some clayey bands. | sparry calcite<br>micrite<br>pelecypod fragments | 89<br>7<br>4 |

| | | |
|---|---|---|
| Marble.--Tertiary metamorphosed Santa Elena Limestone; C-10b; Pinto Tank area. Average grain size 0.01 mm diameter, larger crystals in crack fillings; moderate metamorphism. | sparry calcite<br>fossil fragments<br>pellets | 100<br>tr<br>tr |
| Biomicrite.--Santa Elena Limestone; C-10c; Pinto Tank area. Micrite cement around fossil fragments with sparry calcite filling void spaces; chalcedony between sparry calcite grains; sparry grains to 1.0 mm diameter; broken and rounded fossil fragments from oysters and echinoids; incipient metamorphism. | micrite<br>sparry calcite<br>fossil fragments<br>chalcedony<br>pellets | 55<br>28<br>15<br>2<br>tr |
| Biomicrite.--Santa Elena Limestone; C-12a; Pinto Tank area. Pelecypod and gastropod fragments to 10 mm long; micrite cement with sparry calcite filling void spaces; incipient metamorphism. | micrite<br>sparry calcite<br>fossil fragments<br>chalcedony | 57<br>25<br>18<br>tr |
| Marble.--Tertiary metamorphosed Santa Elena Limestone; C-12b; Pinto Tank area. Rock was biomicrite before weak metamorphism; micrite cement with sparry calcite filling void spaces; clasts average 0.9 mm diameter. | micrite<br>sparry calcite<br>fossil fragments<br>intraclasts<br>clay | 65<br>17<br>16<br>2<br>tr |
| Biomicrite.--Santa Elena Limestone; C-14; Pinto Tank area. Micrite cement with sparry calcite filling void spaces; chalcedony filling cracks; trace of quartz replacement in rudistid fragment; incipient metamorphism. | micrite<br>sparry calcite<br>chalcedony<br>fossil fragments<br>pelecypod fragments<br>quartz | 56<br>28<br>8<br>6<br>2<br>tr |
| Marble.--Tertiary metamorphism of Buda Limestone/Del Rio Formation; C-15; Pinto Tank area. Equant grains average 3 mm diameter. | sparry calcite | 100 |
| Basalt.--Tertiary plug; C-16c; Pinto Tank area. Crytocrystalline to fine | matrix<br>plagioclase | 42<br>32 |

| | | |
|---|---|---|
| grained merocrystalline, porphyritic; plagioclase altering to sericite; pyroxene zoned with titanaugite grading to aegirine-augite on outer edge; magnetite altering to hematite; X-ray analysis of sample of whole rock indicates the presence of analcime, plagioclase, pyroxene, biotite, and amphibole--thus, these minerals probably constitute the matrix. | pyroxene | 13 |
| | amphibole | 6 |
| | biotite | 6 |
| | magnetite | 1 |
| | apatite | tr |
| | hematite | tr |
| | iddingsite | tr |
| | olivine | tr |
| | leucoxene | tr |
| Skarn.--Rim around Tertiary plug; C-16e; Pinto Tank area. Hematite derived from pyrite; fine grained hydro-grossularite porphyroblasts. | chalcedony | 34 |
| | hydro-grossularite | 33 |
| | aegirine-augite | 13 |
| | zeolite (natrolite ?) | 13 |
| | pyrite | 6 |
| | hematite | 1 |
| | apatite | tr |
| | biotite | tr |
| Skarn.--Rim around Tertiary plug; C-16f; Pinto Tank area. Mineral assemblage suggests abundant magmatic juices and therefore a very "wet" magma (Barker, oral communication, 1965). | hydro-grossularite | 58 |
| | chalcedony | 26 |
| | calcite | 15 |
| | hematite | tr |
| | pyrite | tr |
| | wollastonite | tr |
| Skarn.--Rim around Tertiary plug; C-16g; Pinto Tank area. Pyroxene zoned with titanaugite crystals partly altered to aegirine-augite on outer edge; fibrous amphibole. | epidote | 47 |
| | chalcedony | 41 |
| | amphibole | 8 |
| | pyroxene | 2 |
| | magnetite/hematite | 2 |
| | calcite | tr |
| | biotite | tr |
| | leucoxene | tr |
| | plagioclase | tr |
| Skarn.--Rim around Tertiary plug; C-16h; Pinto Tank area. | hydro-grossularite | 55 |
| | calcite | 37 |

| Description | Constituent | % |
|---|---|---|
| | chalcedony | 6 |
| | hematite | 1 |
| | plagioclase | 1 |
| <u>Marble</u>.--Tertiary metamorphosed Buda Limestone; C-17; Pinto Tank area. Original rock was probably a poorly washed biosparite; moderate metamorphism has altered rock such that no fossils remain; hematite pseudomorphs after pyrite or magnetite in form of cubes, rhombs, and octahedrons plus irregular masses. | sparry calcite | 44 |
| | hematite | 33 |
| | micrite | 22 |
| | chalcedony | 1 |
| <u>Marble</u>.--Tertiary metamorphosed Santa Elena Limestone; C-18; Pinto Tank area. Contains fragments of pelecypods, gastropods, and echinoids; sparry crystals average 0.01 mm diameter; original rock was probably a biomicrite; metamorphism moderate. | sparry calcite | 62 |
| | fossil fragments | 38 |

## R E F E R E N C E S   C I T E D


Baker, C. L., and Bowman, W. F., 1917, Geologic exploration of the southeastern Front Range of Trans-Pecos Texas: Texas Univ. Bull. 1753, p. 60-177, 8 pls., 1 tbl.

Barker, D. S., 1965, Oral communication: Dept. Geology, The Univ. of Texas.

Blackwelder, E., 1934, Origin of the Colorado River: Geol. Soc. America Bull., v. 45, n. 6, p. 551-566, 3 figs.

Bloomer, R. R., 1948, Geologic map and structure sections of the Christmas and Rosillos Mountains, Brewster County, Texas: Texas Univ. Bur. Econ. Geology manuscript map without text.

Böse, Emil, 1923, Vestiges of an ancient continent in north-east Mexico: Amer. Jour. Science, 5th ser., v. 206, p. 127-136, 196-214, 310-337.

Brown, T. E., 1963, Index to areal geologic maps in Texas, 1891-1961: Texas Univ. Bur. Econ. Geology publication.

Daugherty, F. W., 1962, Geology of the Pico Etereo area, municipio de Acuña, Coahuila, Mexico: Texas Univ. Ph.D. dissertation, 154 p., 31 figs., 1 pl., 1 tbl.

Donath, F. A., 1962, Analysis of Basin-Range structure, south-central Oregon: Geol. Soc. America Bull., v. 73, n. 1, p. 1-16, 9 figs., 3 pls.

Eifler, G. K., Jr., 1943, Geology of the Santiago Peak quadrangle, Texas: Geol. Soc. America Bull., v. 54, n. 10, p. 1613-1644.

Ellison, S. P., Jr., McBride, E. F., and Thomson, A. (field trip leaders), 1964, The filling of the Marathon geosyncline: Soc. Eco. Paleontologists and Mineralogists, Permian Basin Section, 1964 Field Trip Guidebook, Publication 64-9, 91 p.

Erickson, R. L., 1953, Stratigraphy and petrology of the Tascotal Mesa quadrangle, Texas: Geol. Soc. America Bull., v. 64, n. 12, p. 1353-1386, 4 figs., 5 pls.

Everett, J. R., 1964, Post-Cretaceous structural geology near Del Norte Gap, Brewster County, Texas: Texas Univ. M.A. thesis, 61 p., 15 figs., 1 pl.

Flawn, P. T., Goldstein, A., Jr., King, P. B., and Weaver, C. E., 1961, The Ouachita System: Univ. Texas Publ. 6120, 401 p., 13 figs., 15 pls., 7 tbls.

Flint, R. F., 1957, Glacial geology and the Pleistocene Epoch: New York, John Wiley & Sons, Inc., 553 p.

Folk, R. L., 1961, Petrology of sedimentary rocks: Austin, Texas, Hemphill's, 154 p.

________, 1962, Spectral subdivision of limestone types, p. 62-84, 7 figs., 1 pl., 3 tbls., in Classification of carbonate rocks: Am. Assoc. Petroleum Geologists, mem. 1, 279 p.

Freeman, V. L., 1964, Geologic map of the Indian Wells quadrangle, Terrell and Brewster Counties, Texas: U. S. Geol. Survey Misc. Geologic Investigations Map I-395.

Goddard, E. N., and others, 1951, Rock-color chart: National Research Council, Washington, D. C., distributed by Geol. Soc. of America.

Goldich, S. S., and Elms, M. A., 1949, Stratigraphy and petrology of Buck Hill quadrangle, Texas: Geol. Soc. America Bull., v. 60, n. 7, p. 1133-1182, 6 figs., 6 pls.

Goldich, S. S., and Seward, C. L., 1948, Geologic map of part of the southern Davis Mountains, Texas in West Texas Geological Society Field Trip Guidebook to Green Valley, Solitario, and Barilla Mountains, October 29-31, 1948, p. 16-17.

Graves, R. W., Jr., 1954, Geology of Hood Spring quadrangle, Brewster County, Texas: Texas Univ. Bur. Econ. Geology Rept. Inv. No. 21, 51 p., 4 figs., 8 pls.

Harrison, J. V., and Falcon, N. L., 1934, Collapse structures: Geol. Mag., v. 71, p. 529-539.

________ and ________, 1936, Gravity collapse structures and mountain ranges as exemplified in southwestern Iran:

Geol. Soc. London Quarterly Jour., v. 92, p. 91-102.

Hill, R. T., and Vaughan, T. W., 1898, Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Texas, with reference to the occurrence of underground waters: U. S. Geol. Survey Ann. Rept. 18, part 2, p. 193-321.

Hill, R. T., 1900, Physical geography of the Texas region: U. S. Geol. Survey Topo. Atlas No. 3 (Texas), 12 p.

________, 1901, Geography and geology of Black and Grand Prairies: U. S. Geol. Survey 21st Ann. Rept., part 7, 666 p.

Humphrey, W. E., 1956, Tectonic framework of northeast Mexico: Trans. Gulf Coast Assoc. of Geol. Soc., v. 6, p. 25-35, 1 fig., 1 tbl.

International Boundary and Water Commission, (no date), Geologic strip maps, scale 1:50,000, covering an area about three miles on each side of the Rio Grande from Layitas, Brewster County, to Del Rio, Val Verde County: Texas Univ. Bur. Econ. Geology open-file rept.

King, P. B., 1927, The Bissett formation, a new stratigraphic unit in the Permian of west Texas: Am. Jour. Science, v. 14, p. 212-221.

________, 1930, Geology of the Glass Mountains, Texas, part I: Texas Univ. Bull. 3038, 167 p.

________, 1937, Geology of the Marathon region, Texas: U. S. Geol. Survey Prof. Paper 187, 148 p., 33 figs., 24 pls.

________, 1959, The evolution of North America: Princeton, New Jersey, Princeton Univ. Press, 190 p., 96 figs., 1 pl., 2 end papers.

King, R. E., 1930, Geology of the Glass Mountains, Texas, part II: Texas Univ. Bull. 3042, 245 p.

Longwell, C. R., 1946, How old is the Colorado River?: Am. Jour. Sci., v. 244, n. 12, p. 817-835.

Lonsdale, J. T., Maxwell, R. A., Wilson, J. A., and Hazzard, R. T., 1955, Big Bend National Park, Texas: Midland, Texas, West Texas Geol. Soc., Field Trip, March 18-19, 142 p., 25 figs., 9 pls.

Lozo, F. E., and Smith, C. I., 1964, Revision of Comanche Cretaceous stratigraphic nomenclature, southern Edwards Plateau, southwest Texas: Gulf Coast Assoc. Geol. Soc. Proc. (in Corpus Christi), v. 14, p. 285-307, 15 figs.

Maxwell, R. A., 1965, Oral communication: Texas Univ. Bur. Econ. Geology.

Maxwell, R. A., Lonsdale, J. T., Hazzard, R. C., and Wilson, J. A., (in preparation), Geology of Big Bend National Park, Brewster County, Texas: Texas Univ. Bur. Econ. Geology publication.

McAnulty, W. N., 1955, Geology of Cathedral Mountain quadrangle, Brewster County, Texas: Geol. Soc. America Bull., v. 66, n. 5, p. 531-578, 3 figs., 3 pls.

McDougall, W. B., and Sperry, O. E., 1951, Plants of Big Bend National Park: U. S. Government Printing Office, Washington 25, D. C., 209 p., 190 figs.

Moon, C. G., 1953, Geology of Agua Fria quadrangle, Brewster County, Texas: Geol. Soc. America Bull., v. 64, n. 2, p. 151-196, 4 figs., 4 pls.

Muehlberger, W. R., Denison, R. E., and Hedge, C. E., (in preparation), Geochronology of the mid-continent region, United States; part III - Southern area.

Murray, G. E., 1961, Geology of the Atlantic and Gulf Coastal province of North America: New York, Harper and Brothers, 692 p.

Sanford, A. R., 1959, Analytical and experimental study of simple geologic structures: Geol. Soc. America Bull., v. 70, p. 19-52, 20 figs., 2 pls.

Schofield, D. A., 1965, Qualitative spectrographic analysis of samples 65014 and 65015: report to P. T. Flawn (23 February), director, Texas Univ. Bur. Econ. Geology.

Shambaugh, J. S., 1951, Structure of the Black Gap area, Brewster County, Texas: Texas Univ. M.A. thesis, 60 p., 18 figs., 1 pl.

Smith, C. I., 1965, written communication (16 February and 29 April): Shell Development Company, Alpine, Texas.

Strain, W. S., 1959, Blancan mammalian fauna from Rio Grande Valley, Hudspeth County, Texas: Geol. Soc. America Bull., v. 70, n. 3, p. 375-377.

Udden, J. A., 1907, A sketch of the geology of the Chisos country, Brewster County, Texas: Texas Univ. Bull. 93, 101 p.

Vaughan, T. W., 1900, Reconnaissance in the Rio Grande coal fields of Texas: U. S. Geol. Survey Bull. 164, p. 1-88.

Von Steeruwitz, W. H., 1891, Report on the geology and mineral resources of Trans-Pecos Texas: Texas Geol. Survey 2nd Ann. Rept. for 1890.

Warren, C. R., 1941, Course of Columbia River in southern central Washington: Am. Jour. Sci., v. 239, n. 3, p. 209-232.

Wilson, D. C. O., Jr., 1951, Stratigraphy of Black Gap area, Brewster County, Texas: Texas Univ. M.A. thesis, 98 p., 2 figs., 17 pls., 1 tbl.

Wilson, J. A., 1965, Oral communication: Dept. Geology, Texas Univ.

Yates, R. G., and Thompson, G. A., 1959, Geology and quicksilver deposits of the Terlingua district, Texas: U. S. Geol. Survey Prof. Paper 312, 114 p., 25 figs., 22 pls., 15 tbls.

Young, K. P., 1965, Oral communication: Dept. Geology, Texas Univ.

The vita has been removed from the digitized version of this document.